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THE AGE OF THE EARTH

An Introduction to Geological Ideas

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LONDON: ERNEST BENN LIMITED
BOUVERIE HOUSE, FLEET ST. E.C.

First published February, 1927
Second impression March, 1927
Third impression August, 1927
Fourth impression November, 1927
Fifth impression March, 1928

MADE AND PRINTED IN GREAT BRITAIN BY
BILLING AND SONS, LTD., GUILDFORD AND ESHER

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THE AGE OF THE EARTH

CHAPTER I

THE PROBLEM OF GEOLOGICAL TIME

"The Earth is rude, silent and incomprehensible
at first—
Be not discouraged—keep on."

WALT WHITMAN.

THERE are few problems more fascinating than those that are bound up with the bold question: How old is the Earth? With insatiable curiosity men have been trying for thousands of years to penetrate the carefully guarded secret. Cicero relates that the venerable priesthood of Chaldea held the belief that the earth emerged from chaos more than two million years ago. Man himself, according to the astrologers of Babylon, first appeared nearly half a million years ago. Many of the writers of antiquity did not distinguish the birth-time of the earth from that of mankind. For Lucretius, for example, the world was new, and dated from the time when poets first sang of famous deeds. Zoroaster among the Persian sages limited the past duration of the world to 12,000 years; while the Hebrew chronological tables, as interpreted by Archbishop Ussher, fixed 4004 B.C. as the sacred year of creation. Opposed to these limited ideas of a definite beginning, the old Brahmins of India regarded time and the earth as eternal.

Thus, when the attempt to solve the question first became a definite scientific aspiration, the rival estimates, sentimental, occult, and philosophical, already lay between infinity and a few thousand years. More than a century ago geologists had come to realise that the earth must have had an inconceivably long history, expressible not in thousands, but in millions of years. The record of that history is written in page after page of stratified rocks, and the story disclosed by their study is one of successive changes of life and scene of the most impressive kind.

From the days of earliest tradition down to the close of the eighteenth-century it was commonly believed that the spectacular features of landscapes, such as great mountains and deep gorges, were the result of sudden and violent catastrophes. The terrifying and destructive phenomena of earthquakes, volcanoes, and floods suggested exaggerated ideas of still more terrible convulsions of Nature. Nevertheless, there were more philosophical minds that rejected these imaginary explanations, and entertained the more fruitful notion that the surface relief of the earth might be a consequence of slow but long-continued processes, like those now in familiar operation.

A picturesque illustration of the changes wrought by wind and rain was recorded in 1770 by Jean Guettard, a Frenchman who did much by his careful observations to place geology on a scientific foundation. As a boy in the little town of Etampes, not far from Paris, he played with his companions in the shade of a crag of sandstone which "had been worn by the weather into a rudely formed female figure holding an infant, and had been named by the peasantry the *Rock of the Good Virgin*." Returning after forty years, Guettard found that the crag had gone for ever.

"The rain had beaten, the wind had blown,
The hill was bare as the sky that day.
Mother and Child from the height had gone
'The wind and rain,' said Jean Guettard,
'Had crumbled even the Rock away.'"

ALFRED NOYES.

The weather-beaten appearance of old buildings and the recurrent need for renovations prove that even stones that have been picked for their durability cannot in-definitely withstand the slow attack of wind and rain and frost. These processes and others also act on the land by rotting and disintegrating the rocks, producing waste; and as this is gradually carried away by streams and rivers, the surface of the land is moulded into a landscape and slowly worn down.

Part of every shower of rain sinks into the soil and underlying rocks and promotes the slow work of decay by solution and by loosening the particles. Every frost shatters the rocks with its expanding wedges of freezing water. Every plant-root penetrates the crevices near the surface, and the larger roots help by splitting the rocks beneath the soil; while burrowing animals bring to the surface a great deal of finely comminuted material that is easily washed away by the rain. Wind lifts up the lighter particles and carries them far and wide. From high crags and cliffs sharp-cornered fragments of all sizes fall down under gravity to the slopes below, where they accumulate as temporary screes. The rain gathers into runnels and washes soil and sand, and even gravel, to lower levels. Mountain torrents, clear and sparkling in fine weather, become turbid and brown with earthy sediment after heavy rain, and pebbles and boulders are hurried downstream. Rivers not only carry the load of sediment supplied to them, but they add to it by wearing down their beds and cutting away their sides. And besides their visible burden of mud and sand, their waters hold in invisible solution salts such as the bicarbonates and sulphates of calcium and sodium, materials derived from the decomposition of minerals and from the oxygen and carbon dioxide of the atmosphere.

Thus the lands of the present day are continually being worn away by the processes of denudation. Rivers and other transporting agents carry away the rock waste, and sooner or later it is deposited. Sand blown by the wind is laid down in sand-dunes along the seashore or in the shifting sand-hills of the desert. The materials gathered by glaciers or ground to powder in their slow journey from the ice-fields are dumped down anyhow where the glacier melts, to be dealt with later by running water. In the bends of rivers pebbles, gravels, and sands accumulate; sand and mud are laid down over the flood plains; and, finally, by way of estuary or delta, the balance of the material reaches the sea. There it is distributed and sorted by currents and waves and augmented by the waste furnished to the sea by the unceasing attack of the waves on the cliffs. The coarser material, now smoothed and rounded, collects to form the beach gravels and sands, and out on the sea floor below low-tide mark these narrow fringes of sediment merge into broader bands of silt and mud. In such ways as these sedimentary rocks of different kinds are formed.

On the one hand, the upper levels of the earth's surface are being constantly attacked and worn down by denudation; while, on the other, the depressions are being steadily filled up by the deposition of sediment. The colossal hour-glass of rock destruction on the land and rock formation on the sea floor runs unceasingly.

In this conception of the geological hour-glass we have a clue to one possible method of approaching our problem. If we could measure the rates of denudation and deposition, and compare them with the amount of work accomplished during geological time, then at least a rough idea of the periods of time involved would be gained. Immense systems of strata have already been built up, their maximum thicknesses reaching the almost incredible total of 500,000 feet. How long is it since the earliest pages of these volumes of earth history were written? We shall see in a later chapter how far we have proceeded towards an answer. For the moment it will be sufficient to indicate that vast periods of time must have elapsed since land and sea began their oft-repeated struggle for supremacy.

By measuring the load of sediment transported by a river near its mouth and the amount of mineral matter carried in solution, it becomes possible to estimate the total amount of material removed from the drainage basin in a given time. The Thames, for example, carries to the sea between one and two million tons of rock-waste every year. Similar estimates for other rivers show that our island country is being worn away at an average rate of one foot in 3,000 years. The highlands are lowered more rapidly than the lowlands, but this only accentuates the levelling process. As the average height of Britain is about 350 feet, it is clear that a million years would suffice to reduce the whole country nearly to sea-level.

We therefore see that slowly acting causes, imperceptible as their effects may be in the course of a lifetime, are competent to produce enormous changes if only they are continued through sufficiently long periods. It was this last condition—the necessity for ample time—that led to the long controversy between the Catastrophists and the more enlightened geologists, who believed in the efficacy of existing causes and who were therefore styled Uniformitarians.

In Europe, where theological influence was dominant, the Catastrophists, with their conceptions of great world convulsions, had the apparent support of the Scriptures. The Uniformitarians would not admit that the whole of geological history could be squeezed into some six thousand years, and they were therefore looked upon as dangerous heretics and enemies of religion. Thus the principles of geology were established in the teeth of bitter opposition, and but little headway was made until the battle against the Catastrophists had been fought out and won, less than 100 years ago. Happily, the days of persecution were passing, and it was found that Ussher's famous date had no real authority to justify the zeal with which it had been defended. Christianity lost nothing when the landmark of 4004 B.C. was swept away by the advancing tide of geological knowledge.

It is one of the triumphs of geology to have shown beyond all possibility of doubt that there has been ample time for all the slow transformations of life and scene that the earth has witnessed. Though the problem of the age of the earth has not yet been rigorously solved, yet it has been brought within definite limits, and it is now generally recognised that a million years is to be regarded as a relatively short period in the history of the earth, just as a million miles is a short distance from the point of view of astronomy. The outcome of the labours of four generations of geologists is, as Professor Watts has finely said, "to endow man with a simple and worthy conception of the story of creation, and to fill him with reverence for the wondrous scheme which, unrolling through the ages, without haste, without rest, has prepared the world for man's dominion and made him fit and able to occupy it."

A difficulty that will possibly occur to the reader at this stage may now be conveniently disposed of. We have seen that a million years would suffice to smooth out all the varied scenery of Britain, and we may well ask—if geological time has been so long that a million years is a short period—how it is that rugged mountains and deep valleys still persist. As early as 1692 the naturalist John Ray sagaciously expressed the opinion that ultimately the whole of the land might be reduced below sea-level. Jean Guettard in 1770 went further, and argued that the land and even the sea floor must be uplifted from time to time to compensate for the wastage.

That new land has emerged from the sea is convincingly proved by the presence in many places of typical sea beaches, now raised, with their associated shells, far above the reach of the waves. Along the coast of Peru, and extending sixteen miles inland, uplifted sea beds have been found at altitudes of 200 feet in the south and up to 1100 feet in the north, and the whole series of movements has taken place during the age of man. From another point of view the upheaval of the sea floor with its covering of sediments had been recognised from very ancient times. Six hundred years before our era Xenophanes was impressed by the presence in the hills of Malta of fossil shells that had once belonged to organisms living on the sea floor. Similar evidence has been collected the world over, showing that gradual earth movements—

sometimes involving earthquakes, but not always—have been fully competent to restore the balance of land and sea, which is constantly menaced by the levelling processes. And not only have there been vertical movements, but where the great mountain ranges now raise their peaks to the sky the beds of sediment that gathered on the old sea floors have been folded and crumpled as though between the jaws of an all-powerful vice. The topographical features of every landscape are therefore the result of an incessant struggle which has continued throughout the ages down to the present day, and the rocks formed at different periods by the processes then in operation reveal to us the long history of that struggle. Ovid realised this when he wrote in his *Metamorphoses:*

> "Straits have I seen that cover now
> What erst was solid earth; have trodden land
> Where once was sea; and gathered inland far
> Dry ocean shells."

And Tennyson expressed the same truth in a well-known stanza:

> "There rolls the deep where grew the tree.
> O earth, what changes hast thou seen!
> There where the long street roars, hath been
> The stillness of the central sea."

The problem of the age of the earth can be approached in other ways than that based on the accumulation of the geological formations. We may ask how many of the milestones we call years have been passed by the long procession of ever-changing life. The record of the strata is eloquent of the gradual unfolding of fauna after fauna, culminating at last in the highly specialised organisms of to-day. Yet when we meet with the remains of the earliest forms of life, preserved as fossils in the rocks, we are still far from any record of the solemn moment when life was born on the virgin earth. The work of Darwin and Wallace showed that the time required for the progress of organic evolution was very great. Nevertheless, we are still in doubt as to the causes of the origin of species, and though the rate of change of species may be empirically estimated, as, for example, in the case of the horse and its ancestors, no numerical estimate of the earth's age can be based on such considerations taken alone. The panorama of life in the past implies a vast stretch of time, but it gives at present no more precise information.

We may also ask how long the oceans have existed. Long ago the Royal Astronomer Halley suggested that the oceans had become salt because of their retention of the saline particles annually added to them by the rivers. He foresaw the possibility of an hour-glass method of measuring the age of the oceans, based not on the sands of time, but on the salt of the sea, when he added, "we are therefore furnished with an argument for estimating the duration of all things." In recent years this method has been widely discussed, but there remain difficulties in its application to our problem which have not yet been successfully overcome.

The geological hour-glass methods are all based on a common principle. The rate at which some process is going on at the present day is measured as accurately as possible, and the change produced in, say, one year, is compared with the total effect produced by that process during the interval that has elapsed since its commencement. Unfortunately, whatever process is selected—the deposition of sediments or the accumulation of salt—there remains the difficulty that its rate has not been uniform from year to year. We shall see later how seriously this consideration affects the time estimates which have been based on the faulty assumption of uniform rates.

Moreover, these methods, even if they gave reliable results, would still fail to solve the problem completely. The earth must have existed before the oceans occupied their widespread basins, and the original rocks of the earth's crust appear long since to have disappeared. The oldest known rocks have been invaded from below by molten material that ascended from the depths, and their foundations have been either engulfed or remelted. "As for the earth, out of it cometh bread, and underneath it is turned up as by fire." No evidence of the earth's beginning has yet been detected in any part of the world, and Hutton's oft-quoted dictum, that he could find "no vestige of a beginning," remains true of geology to this day. Geological time dates from the deposition of the oldest known sediments, and whatever their age may be, that of the earth must be still greater.

How far back must we travel in the Time Machine of Mr. H. G. Wells before we can look down on the molten earth, newly formed as a planet in the solar system? This is a problem for astronomy rather than geology, and though to solve it may seem to be a hopeless quest, yet several valiant attempts have been made with encouraging results.

More than half a century ago Lord Kelvin tried to solve the problem by calculating the time that had passed since the earth's surface was too hot for the condensation of the oceans or for habitation by living beings. His calculations were based on what then seemed to be unimpeachable physical reasoning, and geologists were seriously embarrassed when he announced, with all the prestige of his unrivalled authority, that not more than 40 million years could have elapsed since the molten earth solidified. The long controversy that raged around this result is one of the best known of the fierce scientific battles that enlivened Victorian times. Many geologists entertained the forlorn hope that some flaw might be found in Kelvin's argument, but it was not until the early years of the present century that their optimism was justified.

Three surprising discoveries were then made in rapid succession, and they completely upset the validity of Kelvin's results. The first of these was the discovery of radium by Mme. Curie; the second was the discovery by her husband that radium is constantly giving out heat;

and the third was the discovery by Lord Rayleigh that radium is widely distributed throughout all rocks. Thus with the advent of our knowledge of the radio-activity of the rocks it was proved that the earth could no longer be regarded as a simply cooling body, and the suspected flaw in Kelvin's method was revealed. Kelvin's estimates were abandoned with dramatic suddenness. If the earth has indeed cooled down from a molten state—and there are no objections to this traditional view—then it must have cooled far more slowly than Kelvin thought possible. Whatever the age of the earth may be, it must be immensely greater than 40 million years.

And now we reach the most interesting and the most securely founded method of all. The discovery of radium not only destroyed one argument, but it led directly to the most elegant and refined method of measuring geological time that has yet been devised. As we shall see, certain radio-active minerals—more precious than gold—are literally natural chronometers, registering time within themselves, and revealing the passage of hundreds of millions of years since the time when they first took form as part of the rocks and mineral veins in which they occur. In the mechanism of exploding atoms known as radio-activity lies a method for assigning a date to the period of crystallisation of every rock in which suitable minerals can be found. Some of these rare minerals—alike from Norway, Canada, the United States, and Australia—reveal ages of more than a thousand million years, and they are not the oldest. Yet the slowly working leaven of radio-activity enables the earth to renew her youth periodically. The earth has still a long future of activity in front of her, and judged by that standard, to say nothing of the scale of cosmic time in which the terrestrial drama is running its course, she is still young and vigorous.

CHAPTER II

ASTRONOMY AND THE BIRTH-TIME OF THE EARTH

"If one is sufficiently lavish with time, everything possible happens."—HERODOTUS.

IT is evident that on any acceptable theory of the origin of the solar system the age of the sun must be greater than that of the earth, for the earth and her sister planets are universally regarded as the daughters of the sun. Before the doctrine of the conservation of energy was established the steady radiation of light and heat that bathes the earth in a welcome glow was not regarded as a phenomenon to be wondered at. Kant, for example, regarded the sun as a gigantic fire. Yet when the chemistry of fuels came to be studied it was at once realised that the intense emission of energy could not have continued for more than a thousand years or so if combustion alone were the source of radiation. How, then, was it possible for the sun to have continued through countless ages without becoming perceptibly cooler? That it has done so is known beyond possibility of doubt from the evidence of geology. The geographical distribution of fossil plants and coral reefs in past ages betrays no sign of a cooling sun. It is quite certain that for at least as long as the earth has been an habitable globe, so long has the sun emitted its life-giving rays at a rate not very different from that of the present.

The next steps in the search for an explanation were taken by Helmholtz and Kelvin. Their contribution towards a solution was to calculate the duration of the sun's heat on the assumption that its prodigious output of energy was a consequence of the contraction of its mass under gravity. The figures reached varied between 20 and 100 million years, and the same method applied to day with our greater knowledge of the sun's constitution gives more precisely 46 million years. Geologists found no consolation in these depressing studies, for they were left seriously cramped for time. Moreover, if gravitational contraction were all, the twilight of the sun would not be long delayed, and our planet would disappear in the darkness, a barren and frozen world.

Even the discovery of radium failed to ease the position, for if the sun were entirely composed of radio-active elements, the heat generated would not be a third of the actual output. Happily, more recent views lead to a less pessimistic outlook. One of the outstanding achievements of British astronomers during the last few years has been the recognition within the stars—of which our sun is one—of immensely greater sources of energy than had previously been thought available. Always there remain more things in heaven and earth than are dreamt of in our philosophy.

So far as our present knowledge goes, the prolific sources of energy stored up within the atoms are amply sufficient to fulfil every requirement. The energy is released either by the transmutation of elements or by the actual annihilation of mass. In the former case it has been calculated by Professor A. S. Eddington that the past and future life of the radiant sun is limited to 15,000 million years. On the hypothesis of the transformation of matter into energy, inconceivably longer periods of time are possible. The stars themselves are so numerous and represent a gradation from type to type so complete that they can be arranged in a definite evolutionary sequence through which each normal star has progressed or will progress. On the basis of this long-accepted principle, there emerges definite statistical evidence that in the evolution of stars there is a steady loss of mass. The luminosity of a star can be expressed in terms of its mass, and also in terms of the rate of loss of mass in time. Thus it becomes possible to estimate the periods required for any given star to pass through each of the recognised stages of the evolutionary series.

Applying this remarkable hypothesis to the sun, it has been shown by Dr. J. H. Jeans that the present rate of loss of mass is about 1 per cent. in 150,000 million years. Thus the sun's radiation should not have diminished to any appreciable extent during geological time, and, as we have seen, it has not done so. Going still further, Dr. Jeans has reached the conclusion that the ancestral sun has been shining through the universe for something like seven or eight million million years. This astonishing figure passes far beyond the bounds of thought, and, judged by the stupendous scale of cosmic time, even the earth is young, and the longest drafts on the bank of geological time fade into comparative insignificance.

That the age of the universe is to be measured in millions of millions of years follows consistently from three other lines of evidence investigated by Dr. Jeans, relating respectively to binary stars, the velocities of different types of stars, and the internal movements of spiral nebulæ. The argument from binary stars is particularly instructive. These twin bodies appear to owe their origin to the separation of a single contracting body into two stars of unequal mass rotating about each other. Originally the orbits are nearly circular and the twins almost in contact. By the gravitational pull of other stars the orbits become more elliptical, and the eccentricity increases at a rate that can be roughly evaluated. For binary stars in the stage of development known as spectral type F, the period required to produce the observed ellipticity of the orbits is several millions of millions of years. The same conclusion is reached, though more precisely, from a consideration of the masses of the partners. The larger star radiates away its mass more rapidly than the smaller, and consequently the older the binary system the more nearly equal do the two stars become in mass. Type F. binaries have masses in such a proportion that the average age indicated is nearly five million million years.

It is of interest to notice, in passing, that binary stars are now known to be the result of a process similar to that which was originally suggested by Laplace in explanation of the origin of the solar system. According to the famous nebular hypothesis, which dominated cosmic speculations for nearly a century, the solar system evolved gradually from a hot gaseous nebula of lens-like shape, extending beyond the present orbit of the outermost planet and rotating in the same direction as the sun. As the nebula contracted it was supposed to leave behind unstable rings of gas, which ruptured, and condensed into spheroidal planets. The Laplacian hypothesis has been criticised adversely from many points of view, and it is now no longer held. As suggested above, the most conclusive argument against it is that the contraction of a parent mass such as Laplace described would lead, not to the separation of rings, but to a fission into two gaseous stars of unequal masses, thus producing the system known as a binary.

The only theory of the origin of the planets which is satisfactory on dynamical and physical grounds is the tidal theory worked out by Dr. Jeans, and further developed by Dr. Harold Jeffreys. This theory involves the rising of a gigantic tide on the flanks of the ancestral sun due to the close approach of a giant star. From the streams of gas drawn out by the attraction of the wandering stranger the planets coalesced, and began their circulation around the parent body, the sun. The sun in turn acted on the planets, and produced from them the families of smaller bodies known as satellites or moons. The production of a planetary system around a sun is a highly exceptional event, for such is the immensity of space that the close approach of a pair of stars can be but rarely achieved. Dr. Jeans has shown that such an occurrence is not likely to have happened more than once in 1,000 million years, even when all the myriads of stars in the known universe are considered. Thus, until the stupendous age of the sun was realised it seemed likely that the solar system was absolutely unique among the heavenly bodies. But now that the age of the stars is measurable in billions of years, the chances of close approach have been increased thousands of times, and it has become probable that thousands of stars are suns with circulating systems of planets. Our own system can no longer be regarded as unique, for there has been ample time and opportunity for the formation of others.

According to the tidal theory of the solar system, the newly born planets must have moved in highly eccentric orbits in a widely dispersed gaseous medium. The resistance offered by this medium to the circulating planets affected the orbits in such a way as to make them become more and more nearly circular. Now the orbit of Mercury is still far more eccentric than that of the other planets, and this fact suggested to Dr. Jeffreys an ingenious method of estimating the age of the solar system. If the density of the gaseous medium in the neighbourhood of Mercury was D, it is calculated that the time T needed to reduce the orbit to its present shape would be about 4,000/D seconds. But the medium has now almost disappeared—possibly the zodiacal light is the pale reflection from its last attenuated relics—and the time t required for its complete dispersal is about $16D \times 10^{29}$. The two periods T and t must be practically equal, and hence we have approximately—

$$T = t = 4{,}000/D = 16D \times 10^{29} = 8 \times 10^{16} \text{ seconds.}$$

Thus the age of the solar system is found to be of the order 2,500 million years, a result that is remarkably consistent with the evidence of radio-active minerals Naturally a method of this kind cannot be expected to give very exact results, for the data worked into the formulæ are themselves known only within limits. But assuming the truth of the tidal theory, according to which all the planets are of the same age, the age of the earth may safely be placed between 1,000 and 5,000 million years.

Another method of fixing an upper limit to the age of the earth is based on the theory of the moon's origin and history. It is well known that the ocean tides are mainly the result of the moon's attraction. As a consequence of the friction set up by the tides the earth's rotation is very gradually slowing down, and the moon is very slowly retreating from the earth. Therefore, going backwards through time, the moon must be pictured as approaching the earth more and more closely until the two bodies are nearly in contact. It is thus probable, though as yet not securely established, that the moon was derived from the original earth at a time when our planet was newly born and still in a molten state. If this theory be correct, then the date of the separation can be roughly calculated. It works out, according to Dr. Jeffreys, to a few thousand million years.

Still another method, again very insecurely founded, is based on the movement of the solar system across the void of space from its supposed birthplace in the Milky Way. There the stars are more thickly crowded together, and there the chances of close approach are higher than in the comparatively empty region through which the sun is now travelling. In its pendulum-like swing from one side of the stellar universe to the other the sun has now reached a point about one million billion miles from the neighbourhood of the most closely packed stars. The present rate of movement suggests that 2,000 or 3,000 million years would be required for that prodigious journey.

These results are naturally all very speculative and they may be disputed. But they are the best we can reach at present, and it is at least encouraging to find that they are not mutually inconsistent. The age of the earth as a planet, judged from the astronomical evidence, is of the order of a few thousand million years. It is impossible to fix the age within closer limits than 1,000 and 5,000 million years.

If, for the sake of familiar comparison, we liken the age of the sun to its distance from the earth, then the age of the earth would be represented roughly by the circumference of the earth. Man himself has probably over a million years of history behind him, and on this scale of comparison the breadth of London would amply express the whole lifetime of humanity. A single human life of the allotted span would be just about the height of a man, and a year would be represented by an inch.

Practically all the work described in this chapter, involving years of arduous and brilliant research, has been achieved by the present generation of British astronomers and mathematical physicists, and we have just reason to be proud of these explorers through the fathomless depths of space and time.

CHAPTER III

ROCKS AS HISTORICAL DOCUMENTS

"... magic casements, opening on the foam
Of perilous seas, in faery lands forlorn."
KEATS.

IN this chapter we shall return to the earth as we know it to-day, and describe the steps by which geologists have been able to arrange stratified formations in a continuous historical sequence, and to interpret the conditions under which they were formed. The origin of the sands and muds of the sea floor has already been discussed. Other deposits are formed in deserts or in lakes, and lavas are poured from the craters of volcanoes. Wherever a satisfactory parallel can be drawn between older formations and those being formed at the present day, it is argued that the older rocks must have had an origin akin to that of the rocks now in the making. This principle was clearly defined by Hutton in his famous *Theory of the Earth,* published in 1785, when he declared that in the results of the processes going on at the present time lay the key with which to unlock the secrets of the past. The collection of facts gathered from the study of a rock formation thus reveals the geographical and climatic conditions under which it came into existence.

Sun cracks develop in the silts and muds of tidal reaches or flood plains that are periodically dried under a scorching sun. If they become filled with wind-blown sand before the next flood or tide obliterates them, then they may be permanently preserved. Similar structures are found in older beds of corresponding origin. Evidence of rain-storms is provided by the rain-prints that are sometimes found on slabs of fine-grained sediments. As far back as geological history can penetrate such "fossil weather" serves to show that the wind, rain, and sunshine differed in no appreciable way from those of to-day. However, their distribution in climatic regions has often been very different from that of the present.

Smoothed and striated rock surfaces, exactly like those produced by the grinding action of glaciers in the Alpine valleys or in Spitzbergen, and associated deposits of boulder clay, show that much of our country was not long ago under glacial conditions. Similar evidence from very much older rocks in India and Africa proves that in certain far-off ages even tropical lands lay for a time under the frozen spell of ice-sheets. In striking contrast the clay through which the tube railways of London are bored contains relics of tropical vegetation and shells like those of warm Southern seas. In Sheppey remains of crocodiles and tortoises have been found in the same clay, which evidently was formed in the estuary of a great river under tropical conditions. In Greenland rocks containing remains of the breadfruit tree, a typically tropical form of vegetation, have been discovered; and near the South Pole coal occurs, associated with the remains of cone-bearing trees. Where once great forests grew the land is now buried under a wreath of snow and ice.

Built up of innumerable details such as these, historical geology records the rise and fall of land forms; the invasion and retreat of the seas; the growth of deltas and coral reefs; the eruptions of long-extinct volcanoes; and the swing of climate between tropical and glacial; and through all the changes of scene it traces the gradually unfolding development of life, culminating at last in man.

To bring together all the scattered pages of earth history in chronological order is by no means an easy task. The stratified rocks have accumulated layer upon layer, and wherever a continuous succession of beds can be seen it is obvious that the lowest must be the oldest and those at the top the youngest. But the succession is by no means everywhere clear. Faults and folds due to earth-movements have dislocated and twisted the beds in many places, especially among the older strata. Moreover, there are great gaps in the record, as well as innumerable smaller ones. The limestone platforms around Ingleborough can be traced over a wide stretch of country, but where the streams have cut through to the base of the limestone formation it is found lying on the upturned edges of strongly folded slate-like rocks. A junction of this kind is called an unconformity, and it is eloquent of a long interval of time. The underlying beds were deposited on the sea floor as muds and sands. They were gradually folded and crumpled into slates and uplifted high above sea-level in the heart of an ancient mountain range. By denudation they were gradually uncovered, carved into hills and valleys, and ultimately reduced to an undulating lowland. Then the worn-down surface was submerged beneath the sea to become the floor on which the limestones of the Pennines were accumulated.

Unconformities such as this may be represented elsewhere in the world by strata, but even if the missing part of the record were discovered we should be no further on unless we could be sure that it did, in fact, represent the gap in the story. Evidently the different parts of the history which it is the object of geology to piece together must be collected in different regions and placed in their proper order. No single country can be expected to contain all the rocky pages of its history arranged in one complete edition. Other difficulties arise when individual beds are traced from place to place. Except along cliffs and valley sides it is rarely easy to follow a particular formation across country without danger of confusing it with some other similar formation. Further, sandstones may pass into shales, and shales into limestones, though all three may be of the same age, just as the raw materials of each of these types are found to-day accumulating simultaneously on the floor of the North Sea.

In the face of all these sources of ambiguity it is not surprising that little progress was made until it became possible to distinguish the stratified rocks of one age from those of another wherever they might be found. The solution of this problem was the immortal achievement of William Smith, who is known, in honour of his great discovery, as "the Father of English Geology." William Smith was born in Oxfordshire in 1769, and becoming a land surveyor at an early age, his duties soon gave him the opportunity of becoming familiar with the limestones and clays of the Cotteswolds. Within a few years he had worked out the whole succession of the strata between the Severn and the Chiltern Hills. From each bed he carefully collected suites of fossils, and he gradually became convinced that every formation had fossils peculiar to itself. He found he was able to distinguish the Lias, Oxford and Kimeridge Clays, by means of the fossils they contained, and to identify the different limestones. By 1799, after more extended journeys, he had made a list of all the chief formations from the Coal Measures up to the Chalk, and he was able to announce that the suites of fossils contained in them "always succeed one another in the same order."

In France the same discovery was made in the beds around Paris. By 1808 the French geologists had shown that each bed had its distinctive fossils from which its relative age, or position in the sequence, could be told It then became possible to correlate the younger formations of France with those lying above the Chalk in England, and to correlate the older formations of England with those lying below the Chalk in France. The principle of identifying the ages of strata by their fossils has now been tested and applied all over the world. Formations in widely separated regions may be safely regarded as practically contemporaneous when they contain similar groups of fossils.

The long sequence of formations which records the successive stages of the earth's history has been classified into convenient divisions. Just as a book of several volumes is further subdivided into chapters, paragraphs, and sentences, so the larger groups of strata are subdivided into systems, series, and formations; and just as human history may be classified by the supremacy of different nations, and national history by the succession of dynasties and reigns, so geological history is subdivided into eras, periods, epochs, and ages. Two classes of terms are used, because it is desirable to use one for divisions of time and the other for the strata accumulated during those times:

Time terms: Era, Period, Epoch, Age.
Strata terms: Group, System, Series, Formation.

Thus when the Carboniferous System is spoken of, the rocks formed during the time of the Carboniferous Period are meant. In practice, names like *Carboniferous* are often used as though they were nouns instead of adjectives. For example, it is customary to speak of certain rocks—*e.g.*, the Coal Measures—as belonging to the Carboniferous; or of certain organisms as having flourished during the Carboniferous.

In England the series of beds containing the chief coal seams has long been known by the miners as the Coal Measures, and this term has naturally been adopted by geologists for these beds. Beneath them lies a series of massive sandstones and grits which long ago became famous in the manufacture of millstones and grindstones. In consequence they have been given the quarryman's name of Millstone Grit. Underlying this in turn is the Mountain Limestone of the Pennines, now known, wherever it occurs, as the Carboniferous Limestone. As the limestone was traced north through Northumberland into Scotland, it was found to pass into a number of thinner limestone formations, separated by intervening strata which included coal seams. The three series together were therefore styled the *Carboniferous System*, from the Latin words meaning "coal-bearing."

Both above and below the Carboniferous thick beds of red sandstones were known to occur, and these naturally came to be distinguished as the Old Red Sandstone and the New Red Sandstone. The lower formations of the latter, including the Magnesian Limestone of Durham, were found to be of the same age as a vast series of beds occurring in the ancient kingdom of Permia, east of the Volga, a series to which Sir Roderick Murchison in 1841 gave the name *Permian System*. In Germany the upper part of the New Red Sandstone had already been called the Trias, because it was there divisible into three series, consisting of sandstones above and below with an intervening limestone. Although the threefold division is not appropriate in England, since the limestone is absent, the sandstones are, nevertheless, described as the *Triassic System*, a term universally adopted for the rocks of that period despite the purely local significance of the original meaning.

We now come to the limestones and associated clays which William Smith made so peculiarly his own. To the various formations he gave local names, but it was left to the French geologist Brongniart to group them into a system under the name *Jurassic*, from the Jura Mountains, where beds of equivalent age occur. The Cotteswolds, however, remain the classic ground of the Jurassic. The next system, the *Cretaceous*, was also worked out in detail by William Smith. It takes its name from its most conspicuous and widespread member, the Chalk, the Latin word for chalk being *creta*.

To appreciate the meaning of the terms applied to the younger rocks we must go back to one of the earliest attempts to divide up the strata. An Italian, Arduino, in 1760, proposed to classify them into Primitive, Secondary, and Tertiary. The Triassic, Jurassic, and Cretaceous systems are still sometimes referred to as the Secondary group, but for all practical purposes the term has dropped out of use. The name *Tertiary*, however, is given throughout the world to the rocks formed since the Chalk up to the comparatively recent deposits of the Great Ice Age, from which, geologically speaking, we have just emerged. By an extension of Arduino's nomenclature the glacial formations and those of the present day are described as the *Quarternary System*.

It was to Sir Charles Lyell that we owe the subdivision of the Tertiary. He travelled widely from Scotland to Sicily to bring into order the younger formations of Western Europe. In 1829 he met Deshayes, who had already studied the fossils of the Paris basin and compared them with the shell-bearing animals now living in modern seas. From his collection of some forty thousand specimens Deshayes was able to prove that the older Tertiary fossils consist almost entirely of forms that have become extinct, and that as the Recent beds are approached more and more of the fossils become identical with the shells of living organisms. On this basis Lyell divided the Tertiary into three series, and in his *Principles of Geology*, one of the great classics of geological literature, he proposed for them the following names, all derived from the Greek: *Eocene*, meaning "dawn of the recent," with only 3 or 4 per cent. of modern shells represented among the fossils; *Miocene*, meaning "less recent," with about 18 per cent. of recent forms; and *Pliocene*, meaning "more recent," with over 40 per cent. of recent shells.

In 1854 it was found that certain formations were claimed as upper Eocene by some geologists, and as lower Miocene by others. It therefore proved convenient to separate the intermediate beds as a distinct series under the name of *Oligocene*, meaning "few recent."

In 1839 Lyell introduced the further term *Pleistocene* (most recent) for beds with over 70 per cent. of recent species; and later, in 1873, he definitely advised the use of the term for the epoch between the end of the Tertiary Period and the beginning of Recent time. The Recent and Pleistocene epochs are now grouped together as the Quarternary, and, roughly, they correspond to historical time and the Great Ice Age that preceded it. The Quarternary Period is popularly referred to as the "Age of Man." However, recent discoveries of human remains have shown quite definitely that man had already begun to inhabit the earth towards the close of the Tertiary Period.

We must now return to the older systems. At the time when Lyell's *Principles* was published (1830-1833), very little was known of the tangled sequence of the formations below the Old Red Sandstone. The lowest beds of the latter lay with marked unconformity on disturbed and folded rocks like those underlying the Carboniferous Limestone of the North of England. As early as 1822, Adam Sedgwick, encouraged by his friend Wordsworth, began to disentangle the intricate structure of the Lake District. There he discovered the volcanic rocks of Borrowdale lying above the slates of Skiddaw, but he was unable to link them up with the established systems because of the great unconformity that separated the older rocks from the base of the Carboniferous. No one could yet say how many intervening systems might be missing.

Sir Roderick Murchison realised that it was essential to work downwards from the known to the unknown. Having been told by Buckland, his Oxford Professor, that the Old Red Sandstone lay conformably on the older formations in the valley of the Wye, he began his far-reaching explorations in that district in 1831. From the neighbourhood of Builth he traced a long succession of beds to the north-east into Shropshire, past Ludlow and Caer Caradoc to Wenlock, until at last they disappeared under the Triassic plains near the Wrekin.

The names of Wenlock and Ludlow, like those of many another country town of old-world charm, have become part of the romantic heritage of geology, and Murchison's tribute to the bravery of Caradoc and his valiant tribe of Silures has all the beauty of an imperishable memorial. The Silures were the Celtic inhabitants of the Welsh borderlands, and under Caradoc they put up a powerful resistance against the invading legions of Rome. Through treachery, Caradoc himself was delivered to his enemies in the year 50 and sent to Rome. There he exclaimed: "Strange that they who own possessions so many and so splendid should envy us our poor huts." The Emperor Claudius pardoned the British warrior and his family, but they were not allowed to return home Meanwhile the Silures continued to fight for their freedom until Ostorius, the Roman general in charge of the Roman campaign, became impatient at their obstinacy, and declared that the very name of the Silures should be blotted out for ever. Murchison restored that name to a fresh renown when he chose the term *Silurian* for the new system of rocks he had discovered.

While Murchison was working out the details of his Silurian System, Sedgwick was attacking the still older and more complicated slates and grits of North Wales, and from these he established a system for which he selected the appropriate term *Cambrian*. But as the two friends continued their work, it was found that Sedgwick's upper Cambrian contained the same fossils as Murchison's lower Silurian. The resulting clashing of interests led to an unhappy controversy that persisted until Charles Lapworth, in 1879, proposed a solution of the difficulty. The disputed strata was separated from both the original systems and called the *Ordovician* System.

The Ordovices were the inhabitants of North Wales and Anglesey, and long after the Silures had been subjugated, and Boadicea had been vanquished, they resisted the further advance of the Romans until they were practically wiped out among their own hills. As Lapworth persuasively remarked, "How strikingly appropriate is the title of *Ordovician* in erecting a similar scientific monument to the last and most valiant of the old Cambrian tribes."

The Old Red Sandstone was still in an unsatisfactory position after Murchison had created his Silurian System, for it had failed to yield marine fossils, and consequently could not be directly compared with the rocks of other areas. In 1836 Murchison and Sedgwick commenced a joint investigation of the crumpled strata which appear from beneath the Carboniferous in North and South Devon. At first they considered these difficult rocks to be of Cambrian age. However, Lonsdale had been studying the fossils, and particularly the corals, from the same formations, and in 1837 he announced that they were intermediate in character between those of the Silurian and those of the Carboniferous. Murchison and Sedgwick realised the justice of Lonsdale's conclusion, and two years later they established the *Devonian* System, represented in Devonshire by marine strata, including fossiliferous limestones, but elsewhere in Britain by the Old Red Sandstone, deposited in the valleys and lakes of the mountainous country that lay to the north of the Devonian sea.

The Geological Time Scale.—All the fossiliferous strata of Britain had now been arranged in a continuous sequence, and in 1840, Phillips classified the periods into three great eras. For these he extended Sedgwick's *Palæozoic* era, and suggested the new names *Mesozoic* and *Cainozoic* (sometimes written *Cenozoic*) for the later eras, names which broadly express the relations of the life forms then flourishing to those of the present day. They are taken from the Greek *zoe* = life; *palaios* = ancient; *mesos* = middle; and *kainos* (or *cenos*) = recent. The table adjoining shows the general scheme of classification thus completed.

The Chief Divisions of Geological Time with the Maximum known Thicknesses in Feet of the Sedimentary Strata of Each System.

Cainozoic Era (*Modern Life*) - - -	73,000 feet
Quarternary—	
Recent - - - Pleistocene or Glacial	4,000 in Europe
Tertiary—	
Pliocene - -	13,000 in California
Miocene - -	21,000 in California
Oligocene - -	12,000 in Italy
Eocene - -	23,000 in Wyoming
Mesozoic Era (*Mediæval Life*) - - -	91,000 feet
Cretaceous - -	46,000 in Western U.S.A.
Jurassic - -	20,000 in Alaska
Triassic - -	25,000 in Alps and U.S.A.
Palæozoic Era (*Ancient Life*) - -	185,000 feet
Permian - -	13,000 in Australia
Carboniferous -	40,000 in Britain and U.S.A.
Devonian or Old Red Sandstone - -	37,000 in Britain

Silurian	15,000 in Britain
Ordovician	40,000 in Australia
Cambrian	40,000 in Brit. Columbia
PRE-CAMBRIAN ERAS	at least 180,000 feet
Upper Pre-Cambrian Middle Pre-Cambrian	Sometimes grouped as PROTEROZOIC ERA (*Earlier Life*)

Lower Pre-Cambrian or Archæan, sometimes described as ARCHÆOZOIC ERA (*Primæval Life*) or EOZOIC ERA (*Dawn of Life*).

UNRECORDED INTERVAL of unknown duration.

ORIGIN OF THE EARTH.

Although some forms of life are represented throughout the fossiliferous strata, each of the eras has its distinctive groups. The Palæozoic began with the life of the Cambrian rocks, already highly developed. It witnessed the culmination and extinction of graptolites and trilobites; the first appearance of fishes, which became especially abundant in the Devonian; and the clothing of the lands with vegetation. The great forests of the Carboniferous swamps flourished with such vigour that the greater part of the world's coal resources can be traced to their remains. The Mesozoic has often been referred to as the "age of reptiles." Enormous creatures of amazing variety, collectively known as *dinosaurs* (terrible lizards), then roamed the earth, and great swimming and flying reptiles dominated the seas and the air. Among the common fossils, ammonites are practically confined to the Mesozoic. The first birds appeared in the Jurassic, though they differed from their descendants in having teeth. These became extinct at the end of the Cretaceous, together with all the great reptiles. The Cainozoic began with the first appearance of the familiar forms of existing life, and is essentially the age of mammals, toothless birds, and flowering plants.

A number of other "zoic" terms have been proposed, but these have not yet received general acceptance. The Quarternary Period, for example, is sometimes regarded as the beginning of a new era, that of the supremacy of the human mind, to be called the *Psychozoic Era.*

At the other end of the geological column lie vast series of rocks passing down into widespread areas of granites, schists, and gneisses. These ancient rocks have yielded scarcely any fossils, and such obscure remains as have been discovered are of no value for defining worldwide systems. As a result every country has its own names for the subdivisions of these barren and highly altered rocks, and there is no collective name for them all except the general term Pre-Cambrian. The era terms that are now coming into use are given in the table for completeness. It must be remembered, however, that there are few positive relics of organisms in the oldest or Archæan rocks, and that what we do know of their ages in various parts of the world is based on evidence of a totally different kind. Nevertheless, beds of limestone and graphite occur which are difficult to account for except on the assumption that life was concerned in their origin, and it is for this indirect reason that the Archæan has been described as the era of primæval life, or as that of the dawn of life.

We must now briefly refer to igneous rocks; that is to say, rocks like granite and basalt which have ascended towards the surface in a molten state from great cauldrons of magma generated within the heated depths. Lava flows may reach the surface through long fissures or rents and spread widely over the land or across the sea floor. Together with beds of volcanic ash they may build up conical mountains truncated by a crater like the familiar volcanoes of Stromboli and Fuji Yama. Volcanic rocks of the past may therefore be found lying on old land-surfaces or interbedded with ordinary sedimentary rocks. In the latter case they constitute a record of volcanic activity of which the age is that of the strata containing them.

By the recognition of such ancient lava-flows and ash-beds, it has been established that vulcanism broke out in Britain, not once, but many times during its long history. North Wales and the Lake District were great volcanic centres in the Ordovician Period. In the Cheviots we see the worn-down stumps of a volcano of Old Red Sandstone age. Arthur's Seat is the relic of a twin volcano that was built up during the Carboniferous. Finally, early in the Tertiary basalts poured out from Skye to the Giants' Causeway, as they still continue to do, though with diminished energy, in Iceland to-day.

Volcanic activity is only a surface manifestation of the presence below of enormous masses of molten rock material. The vast bulk of these have cooled and solidified below the surface, granite being by far the most abundant type of rock so produced. In many places great intrusions have been laid open to observation, as on the tors of Dartmoor, as a result of the removal by the agents of denudation of the original covering rocks. The origin of granite from a molten condition was established long ago by Hutton by careful observations on the great bodies of granite that occur in Galloway, Arran, and the Highlands. Not only did he discover veins passing from the main mass into the surrounding rocks, sometimes displacing and distorting them, and thus proving that the granite had been forcibly injected into pre-existing rocks, but he also found that the invaded formations had been baked and profoundly altered by the high temperatures to which the molten rock had raised them. Thus it became clear that granite had crystallised from a hot fluid state.

It is not always easy, nor is it always possible, to determine the exact geological age of an ancient intrusion. The igneous rock must, of course, be younger than the invaded rocks, and this consideration limits its age in one direction. An upper limit can sometimes be determined; if pebbles of the rock can be found in a conglomerate, the igneous rock must obviously be older than the conglomerate. The well-known granite of Shap Fells, for example, is easy to recognise because of its large flesh-coloured felspars. Pebbles of this rock are found in the conglomerates at the base of the Carboniferous System near the Shap Wells Hotel, and it is therefore certain that the age of the intrusion is pre-Carboniferous. Since the granite itself has invaded and baked sediments of Silurian age, it must have been intruded from the depths either in late Silurian times or during the Devonian Period.

Although igneous rocks, unlike sedimentary strata, never contain fossils by which they can be dated, some of them contain radio-active minerals. By means of these, as we shall see, it is sometimes possible to ascertain the age of the rocks in years. Thus, if the geological period of the igneous rock is also known, an actual date can be allotted to that period. Radio-active minerals, for the geologist, are clocks wound up at the time of their crystallisation, and by reading these natural timekeepers it is gradually becoming possible to attach a time-scale to the sequence of geological periods. How this has been achieved, and the degree of success so far reached in the reading of the mineral clocks, will be described in a later chapter.

CHAPTER IV

THE GEOLOGICAL HOUR-GLASS

"The ruins of the old land furnished the materials of the new."—HUTTON.

THE direct geological methods that have been devised for measuring geological time are of two kinds. The first attempts to apply a time-scale to the sedimentary rocks, and was historically the earliest to be developed. The second, originally suggested by Halley, but independently discovered and worked out by Professor J. Joly, deals with the accumulation of salt in the oceans. Each method is of the hour-glass type. The one is concerned with sands, muds, and other sediments, carried away from the lands mechanically; the other with the material removed by the rivers in solution.

In order to estimate the rates at which these processes are now going on, it is necessary to make detailed and systematic researches on all the important rivers of the world, or at least of a typical continental area. Measurements are required of—

(*a*) The annual discharge of rivers into the oceans.
(*b*) The salinity of their waters.
(*c*) The load of material carried mechanically.
(*d*) The areas and heights of their drainage basins.

These have been made fairly accurately for many of the world's principal rivers and for the whole of the drainage of North America.

It is fortunate that the mean elevation of North America is very nearly that of all the land areas of the earth. Moreover, its average rate of denudation is but slightly higher than the average for all the measured river basins of the world. We may therefore apply the data for North America with some confidence to all the drainage areas, amounting to some 40 million square miles, of the globe. Doing this, the following results are obtained; they must be of the right order, but they may be slightly too high:

Sediment annually removed from the lands mechanically	6,000 million tons.
Saline matter annually removed in solution	3,000 ,, ,,

When the same quantities are estimated from all the measured regions of the earth—28 million square miles in all—the results are respectively 5,700 million tons and 2,440 million tons. These figures, being a little less than those obtained from the North American data, are likely to be fairly reliable.

Let us now consider Halley's suggestion for determining the age of the oceans. In 1715 the method could not be applied for lack of data, but in 1899, when Joly first proposed to use sodium as an index to the age, the necessary statistics appeared to be forthcoming. Innumerable surveys and analyses carried out in all parts of the world lead to the following figures:

Mass of the ocean waters	1,178,000 million million tons.
Percentage of sodium in the oceans	1·08 per cent.
Total amount of sodium in the oceans	12,600 million million tons.
Sodium added annually by the rivers	156 million tons.

If we adopt the last two figures and make the simplifying assumption that the annual increment of the sodium to the oceans by all the rivers of the world has remained practically uniform throughout geological time, then it is clear that the age of the oceans cannot be greater than

$$\frac{12{,}600 \text{ million million}}{156 \text{ million}} = 81 \text{ million years.}$$

Unfortunately, when the assumptions involved are examined, it is found that the problem cannot be simplified to this extent. Some such figure as 80 or 100 million years has been widely quoted as "the age of the oceans," but it is easy to show that these estimates are not only misleading, but that they are hopelessly wrong. Many geologists have already rejected them as worthless.

The most destructive criticism asserts that the rocks would have to lose more sodium than they had ever contained in order to supply the amounts alleged to be carried annually to the oceans. For all the drainage areas of the world, as we have seen, the best available figures are as follows:

Material carried Annually to the Oceans.	*Millions of Tons.*		*Per cent.*
As sediment - - -	5,700	=	70
In solution - - -	2,440	=	30
Total - - -	8,140	=	100
Sodium in solution - -	156		1·9

The sodium thus represents nearly 2 per cent. of the material brought into the oceans. Now the parent rocks of the material removed from the lands consist of igneous and other crystalline rocks containing 2·85 per cent. of sodium over roughly one-quarter of the drainage areas, and of sedimentary rocks containing 0·81 per cent. of sodium over the remaining three-quarters. The average amount of sodium for all the rocks of the drainage basins is only 1·3 per cent. Even if all the igneous and crystalline rocks were to be denuded as rapidly as sedimentary rocks, which they are not, and if all rocks were to lose all their sodium, which they do not, then the total amount of sodium lost could not exceed 1·3 per cent. Yet the river analyses imply a loss that is very much greater.

In river waters sodium is present only in minute quantities, and even when the utmost care is taken its amount is extraordinarily difficult to estimate by chemical analysis. The tendency of the errors is always to give too high a result. We can only conclude that this particular factor—the amount of sodium added to the oceans—is still imperfectly known. The method of determining the age of the oceans in which it is the determining quantity cannot at present give results of any value.

However, the figures already given suggest a way of avoiding the suspected river analyses. Consider the annual transfer of material from the lands to the sea. The sodium removed from the lands must be accounted for partly as sodium carried in solution and partly as sodium still present in the minerals of the sediments. The first and last of these quantities are tolerably well known, and the sodium carried in solution then comes out by difference at about thirty-five million tons per annum. We now get for the age of the oceans—

$$\frac{12{,}600 \text{ million million}}{35 \text{ million}} = 330 \text{ million years.}$$

Corrections may be applied to such rough computations to take into consideration—

(*a*) The amount of sodium in ground waters, inland lakes, and salt deposits;

(*b*) The wind-borne sodium carried inland as salt from sea-spray;

(*c*) The salt produced commercially and returned to the oceans as sewage or chemical refuse;

(*d*) The increment of salt due to marine erosion;

(*e*) The possibility that the original oceans may have been saline; and

(*f*) The fact the volcanic processes have furnished fresh supplies of sodium salts not taken into account by the statistics of denudation.

None of these considerations, however, is of serious consequence compared with the effect of the assumption originally made. Can we feel assured that the present rates of denudation are characteristic for all time? Has the hour-glass of sediment and salt been running at the same unvarying rate throughout all the vicissitudes of geological history? In recent years it has come to be realised, for a great variety of reasons, that the present rates are far higher than those that have prevailed during the average conditions of past ages. Here are some of the arguments:

(*a*) The continents are now more elevated and the lands are of wider expanse than they have generally been, since we are now near the close or just emerging from a great period of mountain building and continental uplift.

(*b*) The mechanical energy of rivers is therefore abnormally high, and the conditions favour a vigorous circulation of ground waters, which are a very important factor in solvent denudation.

(*c*) In the past denudation, both chemical and mechanical, must have fallen to a nearly negligible value during long periods when the seas invaded the lowlands and the mountains were reduced to low-lying plains. Rivers and ground waters were then sluggish and ineffective. At least since Cambrian times great areas of the existing lands have on balance received deposits rather than supplied them, whereas at present enormous regions are undergoing rapid denudation.

(*d*) Widespread areas in both hemispheres are now covered with easily eroded glacial deposits, laid down during and after the highly exceptional glacial period from which the world is just emerging.

(*e*) Human activities have increased the rate of denudation by the removal of forests and the tilling of soils; by various excavations and engineering projects; and by the addition to the air of various acid gases from factories and fires. Many of the world's greatest and geologically most active rivers flow through thickly populated and highly cultivated lands where previously there were forests that protected the soil.

It is therefore quite impossible to accept present-day conditions as other than exceptionally active. The simultaneous occurrence of so many factors, all leading to more vigorous denudation, has never previously occurred in the world's history, and the age of the oceans must therefore be far greater than the 330 million years here computed on the assumption of uniformity of rate. At the meeting of the British Association in 1921 Professor J. W. Gregory stated that a multiplication by five would not be excessive.

The familiar method of estimating geological time from the maximum thicknesses of the stratified formations is even more difficult to apply with any approach to precision. The figures given on pp. 31-32 add up to the astonishing total of more than 500,000 feet. Beyond assuring us that geological time has been immensely long, these figures help but little towards solving the problem of age, because we do not know, and we cannot know, the rates at which the beds were deposited. To get a preliminary idea of the order of the time implied the work of the Nile may be taken as an example. Since the reign of Rameses II., over 3,000 years ago, one foot of sediment has been added to the neighbourhood of Memphis in Lower Egypt every 400 or 500 years. On this scale the accumulated sands and muds of the geological column would represent about 250 million years. Unfortunately, neither this nor any other estimate of its kind can be taken seriously, for the whole process of sedimentation is far too complex and variable to permit any simple interpretation in terms of averages or maximum rates.

The most important point to realise is that the " thickness " of a formation does not depend only on the rate of supply of sediment, but on the rate of subsidence of the floor or basin where sediments are accumulating. If the floor does not sink to make room for further deposition, then the material is swept further out, and the deposit grows laterally like an advancing railway embankment. The first part of the embankment may have been dumped down in a day or two, but a long stretch may have taken months to complete without any increase of thickness in the embankment as a whole. For the same reason it is impracticable to judge the length of time represented by the apparent thicknesses of formations. Professor J. J.

Sederholm has remarked: "If we mean by maximum thickness the sum of the maxima of the layers formed in successive years, it certainly measures millions of feet."

An instructive case is provided by the sediments laid down in Southern Sweden during the retreat of the last continental glacial of Scandinavia. These deposits have been studied in great detail by Baron de Geer, and his observations have made possible an exact system of geological chronology over the limited period involved. Every spring and summer as the ice thawed a great deal of sand and clay was set free and carried away in suspension by the numerous streams that flowed from the melting ice. The coarser material, on reaching the sea, settled down at once, but the finest particles remained in suspension much longer. Then came the autumn and winter and the freezing of the streams. No further supply of sediment was received, and the load of fine mud slowly settled to the bottom, forming a film of clay, sharply distinguishable from the coarser layer of sand below. The following year the ice again melted, and the front of the glacier retreated. Again two well-marked seasonal layers were deposited. As this process continued year after year, the area of deposit moved northwards with the ice, and the annual twin bands of sediment thus became superimposed one upon another like wedge-shaped tiles on a roof. Seen to-day, when the sea has retreated to the present Baltic, the complete formation is rarely more than 30 feet thick, and no single vertical section includes more than 100 annual layers. Yet the formation includes over 5,000 such layers when it is traced from the coast of Scania up to the mountains where the ice still remains. Are we to say that 30 feet were deposited in 100 years or in 5,000 years? Probably both are wrong, for the same formation continues under the waters of the Baltic into North Germany, where the retreat of the ice first began. The total time represented by the whole areal extent of this thin formation must be more than 10,000 years. Evidently the very terms *thickness* and *rate of deposit* are loose and misleading unless they are very strictly defined.

Another difficulty arises from the fact that the thickest formations can never represent a continuous record of all the time involved. Individual beds may have been deposited very rapidly, as indeed they must have been to ensure the burial and preservation of large fossils. But while the region undergoing sedimentation was stationary or rising, long periods may have elapsed during which sediment was either not deposited or was even removed and carried away to be deposited elsewhere. Most modern beaches show how variable the thickness of sand may be from season to season. The late Professor J. Barrell, who was one of the most brilliant of the younger American geologists, made a very careful study of this question, and showed conclusively that most regions of sedimentation have been subject to alternate scour and fill, and that the actual thickness ultimately preserved is merely the balance left by these two processes. So far from showing a continuous record, the thickest and most rapidly accumulated sediments are thickly crowded with lost intervals, like unconformities on a small scale, each corresponding to changes of climate or of level. The conclusions are reached, contrary to what has often been assumed, that " coarse detritus and rapid accumulation of individual beds is no criterion of rapid accumulation of the formation as a whole," and that " the more rapid the accumulation of individual beds, the longer, relatively, are the times of non-deposition." We may sum up by saying that deposition, if rapid, is not continuous, and that if deposition has been continuous, then in nearly all cases it has been very slow. Quite clearly there is no longer any hope of estimating geological time from assumed rates of deposition and the so-called maximum thicknesses of sediments. Once again we are driven to the conclusion that the periods involved have been many times longer than those usually deduced from this class of evidence.

It is possible to avoid these difficulties by considering the total mass of sediments that has been accumulated, but the method is really only that of the accumulation of sodium in the oceans stated in another and more cumbersome way. The result again works out at about 330 million years, and adds nothing of independent value. The geological hour-glass methods are incapable of providing exact results because the assumption of uniform rates throughout the past cannot be granted. If the present rates are five times greater than the average, then geological time must be of the order 1,500 million years.

CHAPTER V

RHYTHMS AND REVOLUTIONS IN THE EARTH'S HISTORY

"These rocks, these bones, these fossil ferns and shells,
Shall yet be touched with beauty, and reveal
The secrets of the book of earth to man."

ALFRED NOYES.

"THE flight of time is measured by the weaving of composite rhythms: day and night, calm and storm, summer and winter, birth and death—such as these are sensed in the brief life of man. But the career of the earth recedes into a remoteness against which these lesser cycles are as unavailing for the measurement of that abyss of time as would be for human history the beating of an insect's wings. We must seek out, then, the nature of those longer rhythms whose existence was unknown until man, by the light of science, sought to understand the earth. . . . Sedimentation is controlled by them, and the stratigraphic series constitutes a record, written on tablets of stone, of these lesser and greater waves of change which have pulsed through geological time."

In these eloquent words the late Joseph Barrell directed attention ten years ago to a philosophical aspect of geology of which the development had been previously almost wholly neglected. For our purpose the recognition of periodically repeated cycles of earth history is of the utmost importance, for it points the way towards the construction of a more detailed time-scale than has hitherto been possible.

Reviewing the geological history of Britain and Europe on broad lines, we notice a remarkable alternation of landscapes and seascapes. At long intervals great ranges of mountains were formed, but between these times of earth-storm conditions were relatively quiet, and large areas of the present land surface lay beneath the encroaching waters of the sea. Towards the close of the Pre-Cambrian times a land area with mountains and volcanoes existed. A region extending through Scandinavia and Britain then subsided, though with many a minor disturbance, and the thick sediments of the Cambrian, Ordovician, and Silurian Systems were accumulated in a gradually sinking trough. At length the dominant process began to be reversed; the sea floor became raised into land, the accumulated sediments were folded and crumpled, and a great mountain system lay across Scandinavia and the British Isles. The earth movements that brought about this astonishing change are described as the Caledonian Revolution. Gradually the land was worn down again while the Old Red Sandstone was forming from its ruins, but the seas once more began to invade the lower levels of the shrinking lands and wide regions were buried beneath the limestones and other marine deposits of the Devonian and Carboniferous Systems. Then another reversal set in, and the Hercynian Revolution restored the lands and raised a great mountain system across Central Europe. Its relics are found to-day in the older rocks under London, in the coal-field of South Wales, and in the wild hills of South-Western Ireland. For a long time desert conditions prevailed, but the sea again spread widely over the lands, and on its floor another group of systems of strata were deposited. The revolution that brought this third cycle to a close was that which raised the Alps, from the Pyrenees to the Caucasus, and the Himalayas and many another range beyond. We are now again in a continental period, near the climax, or possibly just beyond it.

In the crescendoes and diminuendoes separated by the great revolutions, we see the greatest of the rhythms of earth history. However, the alternation of land and sea has been far more complex than the above simple statement may suggest. Superimposed on the larger waves there have been smaller ones, which nevertheless can be clearly recognised. Time and time again the seas have flooded the lowlands and retreated again, repeating this minor fluctuation perhaps six or seven times within each of the greater cycles marked out by the revolutions. The evidence is read from the breaks in the record due to the tilting or warping of the beds of the sea floor, which caused the withdrawal of the waters and the temporary emergence of land. Some of these minor cycles, which we may speak of as being separated by crustal disturbances, correspond with geological periods, but many of the periods contain more than one, notably the Ordovician and Carboniferous. No doubt in the future the geological record will be reclassified so that the periods and the eras will correspond more closely with the actual rhythms of marine transgression and recession, and the longer cycles determined by the great revolutions.

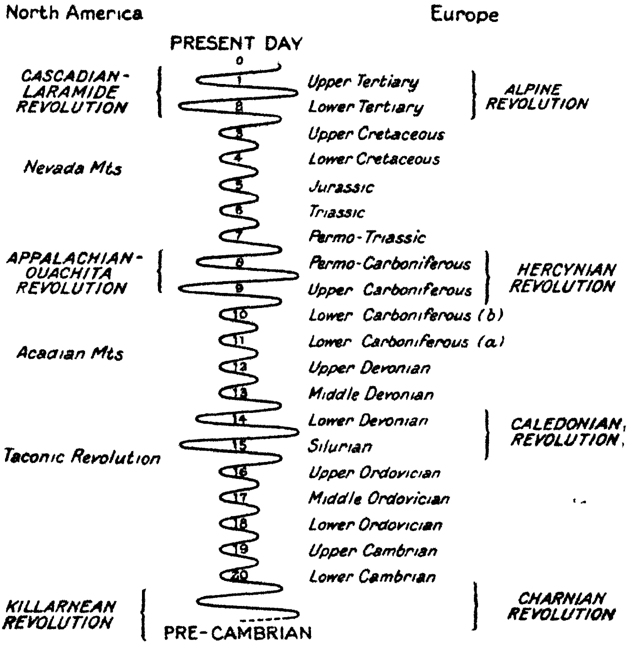
In Europe, since the close of the Pre-Cambrian, there have been altogether about twenty of the minor cycles and three of the greater ones. Similarly, in North America some twenty minor cycles have been recognised. For many years Professor Charles Schuchert has studied the changing geography of North America, and he has been able to plot a wave-like curve showing the extent of each successive invasion of the sea. Exact regularity of recurrence is not, of course, to be expected, and the curves are eloquent of the interweaving of many still smaller cycles. Nevertheless, it is not difficult to distinguish twenty well-marked floods, though some geologists might select only eighteen and others might recognise twenty-two or even more. In the diagram on an adjoining page a list of the cycles is given according to a personal interpretation of the European and American evidence, so far as it is known. It is not pretended that the scheme here adopted is more than a pioneer attempt to disentangle the main cycles from the complexity of the record, but it cannot be far wrong, and it will serve as a basis of discussion.

It may now reasonably be asked whether there is any underlying physical cause for the rhythmic sequence of geological processes which has been detected. Fortunately, owing to an inspired and illuminating hypothesis recently advocated by Professor J. Joly, it is possible to answer this question by an appeal to the radio-activity of the rocks.

It is well known that the rocks of the earth's crust all contain minute quantities of the radio-active elements, thorium and uranium, which, together with their daughter elements (such as radium), are constantly generating heat. The present Lord Rayleigh was the first to point out, as a direct result of his work on the distribution of radium in rocks, that these remarkable facts made it necessary to abandon Kelvin's classical theory of the cooling of the earth. He further showed that it was difficult to believe that the earth is not actually growing hotter. As recently as 1921, discussing the same embarrassing problem, he was obliged to admit that " we are puzzled to explain the existing state of things." Since then Dr. R. W. Lawson and the present writer have discovered that the heat generated by potassium—also a feebly radio-active element—is also of great importance. The evidence makes it seem inevitable that the earth should be growing hotter, yet the geological record is clear that it has not done so. On the other hand, the traditional theory that the earth has cooled down from a molten state has, in its usual simple form, completely failed to explain such important matters as mountain building and volcanic activity. A way out of the impasse has been found by Professor Joly. He persuades us to believe that both heating up and cooling down have taken place. There would be a touch of Irish humour here, were it not that the two processes do not occur at the same time. They alternate, and in the alternation lies the cause of the mysterious heavings and crumplings that have repeatedly affected the earth's outer shell.

In the new theory it is assumed, on well-established grounds, that the continents are vast irregular slabs of granite-like rocks embedded in a deep substratum of heavier rock material having the composition of basalt.

This material is regarded as the source of the great outpourings of basalt which at various times have flooded widespread areas of the continents. The heavy substratum rises around the submerged edges of the continents to form the ocean floors. The deep-seated material is reasonably assumed to contain the same amounts of uranium, thorium, and potassium as the surface samples of basalt which have been collected from all parts of the world and analysed. Thus the temperature must increase downward, as, indeed, it is known to do. At a certain depth the temperature of fusion is reached, and below that depth heat must accumulate until that part of the substratum passes into a fluid state.



The molten rock, or magma, as it is called, gradually works its way towards the surface, where it gives rise to volcanic and other igneous phenomena, and so cools with comparative rapidity. The details would take more space to describe than can be spared, and they are not relevant to our main object; it must suffice to say that the source of the earth's short-period pulsations lies in the alternate accumulation and dissipation of the latent heat of fusion of basaltic material, fusion and expansion being followed in every cycle by consolidation and contraction. As fusion becomes general, the crust as a whole is heaved slowly outwards; but the continents sink a little in the substratum, and their lower levels thus come to be invaded by the transgressional seas. As consolidation supervenes, the outer crust has to settle down on the contracting interior, and the weaker rocks are folded and otherwise deformed like the skin of a withering apple.

At longer intervals, involving perhaps six or seven of the basaltic cycles, the still deeper layers of the earth become fused, and set up a similar process, though on a more extensive scale. To this the author refers the greater revolutions of earth history, marked by the crumpling, overthrusting, and uprising of great mountain ranges and accompanied by igneous activity on an exceptional scale. Extended in this way, Professor Joly's brilliant conception can be matched by its consequences over and over again in the actual sequence of events revealed by the rocky pages of the book of earth.

At the present time the depths are solid (apart from local pockets of magma beneath volcanic regions), a fact that is well established by the passage through the outer half of the earth of earthquake waves that could not propagate themselves through a liquid medium. This state of affairs corresponds with the deduction we have already drawn from present geological conditions—namely, that we are living near the close of a great revolution—that of the Alps and Himalayas—and at a time when the continents have risen and the overflow of the seas has withdrawn. The cycle of changes is ready to begin afresh as renewed heat slowly accumulates in the rocks far beneath our feet.

There is no danger to humanity in this anticipation, for, as we shall now see, the period of each cycle is very, very long compared with human history and pre-history. The immediate object is to attempt to establish a geological time-scale on the basis of the twenty cycles listed on page 49. If each of these is due to a similar process of fusion and consolidation taking place time after time in identical materials, then each of them should represent roughly the same duration of time. That this important deduction is broadly justified will appear from the evidence of radio-active minerals. Meanwhile, we may conveniently return to such geological methods as are available and see where they lead us.

One of the most remarkable estimates of geological time—though confined to the Upper Cretaceous strata of Colorado—is due to the penetrating genius of the late G. K. Gilbert, who was one of the most notable of American geologists. In the 3,900 feet of shales making up the Benton, Niobrara, and Pierre groups, he detected a pronounced alternation of limestone and calcareous shale recurring at four stages. In the first the rhythm is repeated fifteen times, each limestone bed with its thin shale having an average thickness of 18 inches. Where the limestones are less pure, as in the upper stages, the thickness of each rhythm averages 32 inches. For the intervening shales the equivalent thickness of a rhythm was calculated to be about 4 feet. Now the only regular rhythm in nature which seemed adequate to explain the alternating conditions implied by the rhythmic sedimentation was that due to the precession of the equinoxes, with a period of 21,000 years. Feeling convinced that he had stumbled upon the beating of the precessional clock, after rejecting all other possibilities as unreasonable, Gilbert calculated the rates of deposit of the beds at 1 foot in 5,000 years for shale, and 1 foot in 14,000 years for limestone—figures that are by no means unreasonable for slow deposition far out at sea.

On this basis the 3,900 feet of the investigated series represent 20 million years, and as they constitute only two-thirds of the whole of the Upper Cretaceous beds, we may conclude that the complete Upper Cretaceous cycle of marine invasion and withdrawal (No. 3 on page 49) required some 30 million years.

In North America the Tertiary Period appears to consist of two cycles, unusually complicated by the growth of mountains, but still recognisable. Two rough methods, quite independent of astronomical or radioactive phenomena, are available for estimating the duration of these cycles.

Mr. J. E. Spurr, one of America's greatest mining geologists, has drawn attention to the enormous amount of denudation that has been necessary to uncover the early Tertiary ore-deposits of Colorado. At Aspen, in that State, widespread erosion has removed at least 15,000 feet of rock, and other mining areas provide confirmatory evidence. The present rate of denudation in North America averages about 1 foot in 8,600 years. But regions like Colorado, as it is and as it was, are worn down more rapidly. A fairer average rate for such regions is 1 foot in 3,000 or 4,000 years. This estimate would make the Tertiary Period longer than 45 million years, with 60 million as a more probable figure. Here again we get roughly 30 million years for each of the two cycles, and there are no grounds for adopting a figure much below this.

Still another method is based on presumed rates of organic evolution. The development of the horse from the little terrier-sized Eohippus that roamed the first prairies of the early Tertiary has been traced out in admirable detail right down to the present day. Professor Matthews, than whom no one is better qualified to judge, has estimated that the changes must have taken at least a hundred times as long as those that have occurred since the first great glaciers advanced from the north in the great Ice Age. Now the evidence in America suggests that more than 400,000 years have elapsed since the beginning of the Glacial epoch, and in the Alps more than 460,000 years are indicated. In each case there is a part of the record for which no estimate can be satisfactorily made, and some geologists would allot as much as a million years to the age of ice. This is probably excessive, and 500,000 years, though a conservative estimate, is more in accordance with recent work. Adopting this, Professor Matthews' work gives us at least 50 million years for the Tertiary Period, in good accord with the result based on denudation in Colorado.

It should now be clear that, in round figures, 30 million years satisfies all the available data for each of the three cycles that make up the Upper Cretaceous, Lower Tertiary and Upper Tertiary. If, as we have seen to be probable, the periods of all the cycles are of the same order, then the twenty that have been completed since the beginning of the Cambrian must represent about 600 million years. The longer cycles of the great revolutions average 150 to 200 million years each, and as there were at least four of these before the Cambrian began, we see that the age of the earth may far exceed 1,000 million years. From purely geological considerations we are at last approaching figures like those given by the older radio-active minerals, and to the consideration of these we shall now turn.

CHAPTER VI

THE RADIO-ACTIVE TIMEKEEPERS OF THE ROCKS

" Man putteth an end to the darkness, and exploreth to the utmost limit the stones of darkness."—*The Book of Job.*

In the year 1896 the French physicist Becquerel made the remarkable discovery that uranium salts and minerals give out invisible rays which are capable of penetrating black paper and of revealing their existence by their effect on a photographic plate wrapped within it. Mme. Curie followed up this epoch-making observation by an exhaustive examination of all the elements then known, and she was soon able to announce that thorium alone possessed radio-active properties comparable with those of uranium. In the course of her researches, Mme. Curie found that uranium-bearing minerals, such as pitchblende, were far more active in their emission of rays than could be explained by the amounts of uranium present. This curious and significant discrepancy was the starting-point of a further search which led to the discovery of radium and other rare radio-active elements. To-day we know of the existence of over thirty of these elements, all of which belong to two main families having uranium and thorium as the parents. There is also a subfamily called the actinium series, which probably branches from the uranium series, forming about 3 per cent. of the complete family.

The spontaneous radiations that are emitted were found by Sir Ernest Rutherford to be three types, which he distinguished as Alpha-rays, Beta-rays and Gamma-rays.

Alpha-rays are electrically charged atoms of helium, explosively ejected with velocities of thousands of miles per second.

Beta-rays are electrons, having a mass less than a thousandth of that of a hydrogen atom, and expelled even more swiftly than the alpha-particles.

Gamma-rays are not material particles in rapid motion, but are of the same nature as X- or Röntgen-rays.

Professor A. C. Lane has suggested a way in which anyone with a luminous watch can see the results of radio-activity in visible operation. "Take your wrist watch or a compass that shines in the dark. After your eyes are made sensitive by sitting in a dim light for ten minutes, and then in darkness for a minute more, look at it with a good pocket lens. You will find it quivering with light. After a while, if your lens magnifies ten diameters or so, you will see that it is made up of countless sparks, like those from a bursting rocket. Each one of these represents the explosion of an atom, and the helium particle sent off, striking the sensitive zinc sulphide, makes it glow."

In 1903 Professor Soddy and the late Sir William Ramsay directly proved the generation of helium from a radium preparation that was originally quite free from the gas. In the same year it was discovered in Paris that radium is constantly giving out heat, and the source of the greater part of this evolution of energy was traced to the high velocity of the expelled helium atoms. Now if an atom of radium loses an atom of helium and part of its hidden store of energy, the atom that remains must be transformed into something different. Close examination revealed the genesis of a new element, a gas known as radium-emanation. This in turn breaks down, and in its place another element, Radium A, arises. A long succession of similar transformations has been traced, each accompanied by an explosive liberation of energy and in many cases by the expulsion of helium.

It was found, for example, that even radium does not exist of itself, but that it is constantly being formed as one of the series of daughter elements which arise from the disintegration of uranium. After three atoms of helium have been discharged in the line of descent from uranium, radium is reached. This in turn decays, and a state of equilibrium is established in which the amount newly generated and the amount lost by decay become equal. Ultimately, when eight atoms of helium have been expelled, the genesis of unstable derived elements comes to an end, and a stable, inert, end-product is left which is chemically identical with lead.

The whole active family is then in a state of equilibrium, as a result of which there is a constant ratio between the amount of uranium present and that of each of the unstable daughter elements. The ratio of uranium to radium, for example, is about 3,000,000 to 1, and this explains why radium is so rare an element. Even if a mineral consisted originally of pure uranium it could not contain more radium than 1 part in 3,000,000. When the whole family is in equilibrium, the disintegration of one atom of the parent uranium implies the decay of one atom of each of the unstable derived elements, and the generation of eight atoms of helium and of one atom of lead. The helium and lead, being stable, gradually accumulate as their ancestor, uranium, is slowly destroyed.

It is this fact which makes possible the method of measuring geological time to which allusion has been made in previous chapters, and which we shall now proceed to examine. The radio-active elements have already been likened to clocks kept going by springs that gradually unwind themselves. But while a clock records time in ticks that are heard and pass away, the radio-active elements are engaged in keeping a more material register of time, after the manner of an hour-glass, the accumulating materials being helium and lead. Every radio-active mineral may thus be regarded as a natural chronometer, registering time by the atoms of helium and lead that are unceasingly produced within it year after year.

Lord Rayleigh measured directly the rate of formation of helium in various minerals, having first ascertained the amount of helium which had accumulated in each. By experiments extending over several months he was able to show that a gram of uranium generates helium at the rate of 1 c.c. in nine million years. In the case of thorium he found nearly three times as long to be required to produce the same volume of the gas. A mineral called thorianite, from Ceylon, originally contained 286 million times as much helium as the same mineral could generate in a year. Evidently, at a steady rate of production, that large volume of helium must have taken 280 million years to accumulate.

We shall discuss later the justification for the assumption that the rate of production has not appreciably varied during geological time. A more serious difficulty remains. Can we be sure that no helium had escaped from the mineral during the period elapsed since its crystallisation? Unfortunately we cannot. Helium is a gas, and it has been experimentally demonstrated that as soon as any radio-active mineral is exposed to the air it begins to lose part of the concentrated gas stored within it. When it is powdered for chemical analysis, still more helium leaks away. Consequently the helium actually found in a mineral can be only a fraction of the total amount generated during the lifetime of the mineral.

Returning to the thorianite investigated by Lord Rayleigh, it would clearly be erroneous to suppose that its age is only 280 million years. Its age must be far higher than that. Thorianite occurs in certain sands and gravels in Ceylon, where it has been exposed to the action of the weather for thousands of years—ever since it was first broken away from its original home in the coarse granite dykes of the island. During all that time its store of helium has been leaking away, and present-day measurements therefore give only a minimum estimate of its age.

Fortunately, lead, the end-product of the radio-active elements, is much less liable to escape. The ultimate change from uranium to lead may be represented thus by an atomic equation:

$$\begin{array}{ccc} \mathrm{U} & = \mathrm{Pb}\mu & + 8\mathrm{He} + \text{energy}. \\ \text{Uranium.} & \text{Lead.} & \text{Helium.} \\ 238\cdot2 & 206 & 8\times4 \end{array}$$

The figures represent the atomic weights of the elements concerned, and show that 238·2 parts of uranium produce 206 parts of lead in the same time as 32 parts of helium. Hence, from the known rate of production of helium from uranium, it can easily be calculated that a million grams of uranium give rise to $\frac{1}{7400}$ of a gram of uranium-lead every year.

Thus, if we know by analysis the percentage of uranium, U, in a mineral and that of the uranium-lead, Pbμ, which has accumulated within it, then the time required for the accumulation is given to a first approximation by the simple formula—

$$\frac{\mathrm{Pb}\mu}{\mathrm{U}} \times 7{,}400 \text{ million years.}$$

This formula (like those that follow) is subject to a slight correction to allow for the obvious fact that when the mineral first crystallised the original amount of uranium present must have been a little greater (U + Pbμ + He) than the amount (U) now remaining.

It will be noticed that the atomic weight given for lead derived from uranium is 206, whereas that of ordinary lead is 207·2. That this difference of atomic weight is real has been established beyond doubt by actual determination on lead separated from uranium-bearing minerals in which the stable end-product had accumulated through long geological periods. Chemically the two leads are otherwise identical, but the atomic weight difference provides a valuable means of discriminating between the ordinary lead of commerce (such as that occurring in the common lead ore, galena) and that generated by uranium.

Thorium also disintegrates through a long series of descendents in a manner closely analogous to that of uranium, but helium is given off at only six stages, and the end-product is another variety, or isotope, of lead, having in this case an atomic weight of 208. The ultimate change may be expressed thus:

$$\begin{array}{ccc} \text{Th} & = & \text{Pb}\theta + 6\text{He} + \text{energy.} \\ \text{Thorium.} & \text{Lead.} & \text{Helium.} \\ 232 & 208 & 6 \times 4 \end{array}$$

The rate of production of helium from thorium shows that a million grams of thorium give rise to only $\frac{1}{19500}$ of a gram of thorium-lead in a year. Thus, if the percentages of thorium and of thorium-lead in a mineral are Th and Pbθ, then the time required for the accumulation of the lead is given very nearly by—

$$\frac{\text{Pb}\theta}{\text{Th}} \times 19{,}500 \text{ million years,}$$

or by

$$\frac{\text{Pb}\theta}{0 \cdot 38 \text{ Th}} \times 7{,}400 \text{ million years,}$$

provided, as before, that the rate of disintegration has not varied in the past.

When, as usually happens, both the parent elements, uranium and thorium are present in a radio-active mineral, the time required for the accumulation of all the lead, represented by (Pbμ + Pbθ) or more simply as Pb, is given by the combined formula—

$$\frac{\text{Pb}}{\text{U} + 0 \cdot 38 \text{ Th}} \times 7{,}400 \text{ million years,}$$

subject, as before, to the small correction for the wearing out of the parents during the lifetime of the mineral.

The ratio Pb/(U + 0·38 Th) is conveniently referred to as the "lead-ratio." It will now be clear that all unaltered primary radio-active minerals (that is to say, minerals that crystallised out with the rock whence they came, and that have not since been subject to chemical interference by natural agencies such as weathering and volcanic processes) should have the same lead-ratios if they date from the same geological period. Further, unaltered primary minerals of greater geological age should have higher lead-ratios than those belonging to more recent periods. These deductions are well supported by the actual evidence. Such apparent discrepancies that occur can generally be traced to the absolutely essential condition of freshness not having been fulfilled.

The various assumptions that are implied in the calculation of the age of a mineral from its lead-ratio must now be carefully examined. Can we feel assured—

(*a*) That no lead was originally present in a radio-active mineral at the time of its genesis by crystallisation?

(*b*) That no lead has been removed from the mineral since its crystallisation or added to it from an external source?

(*c*) That both uranium and thorium have disintegrated at the same rate throughout geological time?

The answer to the first question (*a*) depends on the mineral associations of the actual specimens analysed. Ordinary igneous rocks and the great majority of pegmatites are free from all but negligible traces of lead. Many radio-active minerals, such as uraninite and its many varieties, occur in pegmatites that contain no galena, the common ore of lead. The atomic weight determinations of lead separated from certain uraninites show, by their close approach to the theoretical value 206, that ordinary lead (207·2) is absent, and can therefore never have been present. In other cases a very small amount may be indicated, though insufficient to affect seriously the age determinations. The figure actually found for the atomic weight is always slightly above 206 in even the most favourable cases, since it rarely happens that a uranium mineral is absolutely devoid of thorium.

ATOMIC WEIGHTS OF LEAD FROM URANIUM MINERALS

Mineral.	*Analysts.*	*At. Wt.*
Pitchblende, Katanga.	Hönigschmid and Birckenbach.	206·048
Uraninite, Morogoro.	Hönigschmid and St. Horovitz.	206·046
Bröggerite, Norway.	,,	206·06
Uraninite, S. Dakota.	Hall and Richards.	206·07
Cleveite, Norway.	Richards and Wadsworth.	206·08
Bröggerite, Norway.	,,	206·12

Some varieties of pitchblende occur in mineral veins, and may be intimately associated with galena, as, for example, at St. Ives in Cornwall, and at Joachimsthal in Czecho-Slovakia. In these cases there is no doubt that ordinary lead was originally present in the radio-active mineral. But fortunately the atomic weight of the lead separated from an impure mineral of this kind serves to show the proportions of ordinary lead and uranium-lead. The pitchblende of Joachimsthal, for example, is so nearly free from thorium that complications due to thorium-lead can be ignored. It gives a gross lead-ratio of 0·042. The atomic weight of the lead has been determined by Professor Hönigschmid, and the value found, 206·4, shows that one-third of the lead is ordinary lead (207·2) and that only two-thirds is uranium-lead (206). The corrected lead-ratio thus becomes 0·028. The difficulty implied by the possible presence of original lead can thus be overcome by atomic-weight determinations.

The second assumption (*b*) is less easily dealt with. If a series of fresh primary minerals from rocks of the same geological age give the same lead-ratio throughout, then it becomes highly probable that the minerals have neither lost lead nor gained it during their geological history. For had they done so, the effects would have varied from place to place and the lead-ratios would then also have varied. The effects of alteration, in cases where it has been clearly recognised, are shown by the following analyses:

LEAD-RATIOS OF FRESH AND ALTERED MINERALS

Mineral.	*U*	*Th*	*Pb*	$\frac{Pb}{U+0{\cdot}38Th}$
Uraninites, Canada:				
1. Villeneuve	64·74	6·41	10·46	0·154
2. Parry Sound ...	69·19	2·83	10·83	0·152
3. Parry Sound ...	66·12	2·94	9·76	0·143
4. Butt Township ...	66·02	1·08	9·82	0·146
5. Butt Township ...	64·24	0·71	9·62	0·147
6. Cardiff, decomposed	55·26	11·92	10·25	0·169
Arendal District, Norway:				
1. Uraninite	61·27	3·65	10·16	0·162
2. Nivenite	56·25	6·66	9·40	0·160
3. Uranothorite ...	8·80	45·50	1·55	0·160
4. Uraninite, altered	55·05	3·22	9·78	0·172
5. Cleveite, altered ...	54·00	4·05	10·16	0·183

In each suite of uranium minerals, and the rule appears to be general, the effect of alteration appears to be to raise the lead-ratio, as though uranium had been removed in greater amount than lead.

Amongst series of thorium-rich minerals, however, this rule does not apply, and indeed no constancy of ratio can be depended upon, even when the minerals seem to be fresh. So striking is the contrast in this respect between uranium minerals and thorium minerals that Dr. Lawson and the author concluded in 1914 that lead was probably not the end-product of the thorium series. In 1918 Professor Soddy suggested that only 35 per cent. of the end-product might be lead. Later work, however, has shown that there is no satisfactory alternative to the view that lead is, in fact, the stable end-product. Nevertheless, thorium minerals give results that are so little trustworthy that they have been used to cast doubt on the reliability of the whole method, or alternatively to suggest that the lead-ratios of uranium minerals are too high as indices of age. Some minerals from Ceylon provide an instructive example:

Lead-Ratios of Radio-Active Minerals
from Ceylon

Mineral.	*U*	*Th*	*Pb*	$\frac{Pb}{U+0\cdot38Th}$
1. Pitchblende ...	71·40	7·86	4·75	0·066
2. Thorite	4·57	62·8	1·28	0·045
3. Thorite	3·50	59·2	0·78	0·029
4. Thorite	1·62	54·4	0·36	0·016
5. Thorite	1·88	65·4	1·71	0·064

Professor Joly has argued that the ratio of No. 4 may be more reliable than that of No. 1, which is four times as high. The thorite gives an age of 120 million years and the pitchblende indicates 488 million years. Which are we to adopt, if either? Now, in the first place, there is no reason for assuming that the minimum result given by No. 4 is likely to be more accurate than the ratio 0·064 given to No. 5. Quite the contrary, for the latter ratio is practically identical with that of the pitchblende. In the second place, the average of fourteen other ratios of thorianites is 0·063, the range being from 0·047 to 0·074. Thus the evidence for the whole suite of minerals for Ceylon favours the adoption of a ratio which is above 0·06, and makes it necessary to find some explanation for the low values given by some of the thorites.

A recent scrutiny of all the available data, based on analyses and atomic weight determinations, points to the probability that thorium minerals tend to lose lead by the variable action of minute quantities of water percolating through their crystal network; and, moreover, that thorium-lead is extracted in preference to uranium-lead. But both uranium-lead and thorium-lead have chemical properties that are identical with those of ordinary lead, and it may seem incredible that one should be removed from a mineral in greater relative amount than the other. Nevertheless, this seems to have happened. Three of the analysed thorianites from Ceylon are of special interest, as they represent the actual materials from which three samples of lead were extracted for atomic weight determination. These analyses and the atomic weights determined by Honigschmid are given below:

LEAD-RATIOS OF THORIANITES FROM CEYLON AND ATOMIC WEIGHTS OF THE MIXED LEAD FROM EACH

	U	*Th*	*Pb*	$\frac{Pb}{U+0\cdot38\,Th}$	*At. Wt. of Pb*
1.	26·8	57·0	3·5	0·072	206·84
2.	20·2	62·7	3·11	0·071	206·91
3.	11·8	68·9	2·34	0·062	207·21

The atomic weight 206·84 implies that the mixed lead consists of 58 per cent. uranium-lead plus 42 per cent. thorium-lead. Thus the amount of each isotope of lead can be calculated, and the age computed from each separately:

No. 1—

$$\left.\begin{aligned}&\frac{58\%\text{ of }3\cdot5}{26\cdot8}\times7{,}400=562\text{ million years.}\\&\frac{42\%\text{ of }3\cdot5}{57}\times19{,}500=500\text{ million years.}\end{aligned}\right\}$$

Similarly, from the other two analyses, we find—

No. 2—

$$\left.\begin{aligned}&\frac{\text{Uranium-lead}}{\text{Uranium}}\times7{,}400=614\text{ million years.}\\&\frac{\text{Thorium-lead}}{\text{Thorium}}\times19{,}500=450\text{ million years}\end{aligned}\right\}$$

No. 3—

$$\left.\begin{aligned}&\frac{\text{Uranium-lead}}{\text{Uranium}}\times7{,}400=577\text{ million years.}\\&\frac{\text{Thorium-lead}}{\text{Thorium}}\times19{,}500=410\text{ million years.}\end{aligned}\right\}$$

In each case the age calculated from the uranium-lead is considerably higher than that calculated from the thorium-lead. This can be explained most readily on the hypothesis that from each mineral part of the thorium-lead has been lost.

It follows from the above considerations that in minerals the lead formed from uranium should exist in a relatively insoluble compound, and that the lead generated by thorium should exist in a more soluble compound. Now, when an atom of lead comes into existence in the crystal lattice of uraninite, it must be surrounded by atoms of uranium and oxygen; that is to say, it is in an acidic environment. Helium, being inert, need not be considered. It seems probable, therefore, that the general association of atoms should correspond to the assemblage required to form a molecule of lead uranate. At first the arrangement of atoms would be haphazard, but if water passed slowly through the crystal, the resulting localised mobility and kinetic exchange would promote at each point the formation of the most insoluble compound possible; that is to say, lead uranate.

In thorium minerals the lead could not form a thorate, as thorium and oxygen do not constitute an acidic environment, and corresponding with this no thorates are known to exist. In thorianite the lead should be largely present as an oxide; and in thorite partly as oxide, and partly perhaps as a silicate. In both minerals the most probable lead compounds are therefore of a comparatively soluble type.

In mixed minerals, such as thorianites rich in uranium, the tendency to loss of lead should be less than in thorites poor in uranium, as we find to be the case. This follows from the fact that the thorium-lead migrating out of a thorianite must pass through an assemblage of atoms many of which are uranium and oxygen. Part of the lead which would otherwise escape should thus be arrested and fixed as lead uranate. In thorites the corresponding capacity to retain lead is practically negligible.

The hypothesis of preferential leaching is thus in accordance with chemical probabilities, and for the first time the long-puzzling discrepancies between thorium and uranium minerals appear to receive an adequate explanation.

RADIO-ACTIVE MINERALS FROM LLANO CO., TEXAS

Mineral.	*U*	*Th*	*Pb*	$\frac{Pb}{U+0{\cdot}38Th}$
1. Uraninite	55·18	5·90	9·35	0·163
2. Uraninite	56·45	6·66	9·43	0·160
3. Mackintoshite ...	19·75	39·86	3·47	0·099
4. Thorogummite ...	19·70	31·40	2·01	0·063

Each group of doubtful minerals must be judged on its own merits by a full consideration of all the evidence. The minerals from Llano Co., Texas, constitute a series which, with the exception of the uraninites, is far from fresh. The two thorium minerals listed above show the tendency to loss of lead by giving much lower ratios than the uraninites. It is also noteworthy that No. 4 is a yellowish brown residual mineral produced from No. 3 by oxidation and hydration. Corresponding to this change the lead-ratio of thorogummite is lower than that of mackintoshite. The uraninites, on the contrary, are abnormal neither in oxidation nor in hydration, showing that their lead-ratios are not likely to have been vitiated by leaching out or introduction of lead.

In general, thorium minerals are suspect unless there are good grounds for adopting their testimony. Uranium minerals may or may not be reliable according as they are fresh or altered and according as the lead-ratios of a suite of minerals from rocks of the same age are concordant or discordant. In each case the value for age determination is greatly increased by atomic weight determinations.

The third assumption (*c*), referred to on page 60, can be best discussed from the point of view of pleochroic haloes, and as an introduction to this fascinating topic we may consider the work of twenty years ago on their nature and origin.

The presence of uranium and thorium in rocks is sometimes revealed in a most beautiful way. When mica and tourmaline and a few other minerals are examined in thin sections under the microscope, small ring-shaped or disc-like marks known as pleochroic haloes are sometimes seen. At the centre a minute crystal of zircon or of some other radio-active mineral can usually be detected. In 1907 Professor Joly demonstrated beyond doubt that these intensely pleochroic spots were due to the radioactivity of the tiny inclusions at their centres.

The alpha-rays, or helium atoms, discharged from the different radio-elements have not all the same velocity. Those from uranium can penetrate about one-seventieth of a millimetre of mica, and they give up most of their electrical charge just before coming to rest. Since they must be discharged equally in all directions they come to occupy a spherical surface around the central uranium. The helium atoms from radium travel more rapidly and thus penetrate farther, forming another spherical surface. Those from radium C have the maximum range and form a sphere which encloses all the others. The ranges of the helium atoms from the thorium family are of the same order, but slightly greater than those from the uranium family, and consequently the resultant spheres are of somewhat greater diameter.

The distance to which a helium atom can penetrate depends on the density of the matter through which it is passing. The ranges in air have been carefully measured, and the corresponding values for biotite can easily be calculated. The largest sphere from the uranium family should have a diameter of 1/30 mm., and that from the thorium family a diameter of 1/25 mm. Now the maximum diameters of haloes have been carefully measured, and surely enough there are two types of haloes with exactly the diameters theoretically to be expected. Clinching the argument by practical demonstrations, Sir E. Rutherford has made artificial haloes in glass and in flakes of biotite.

The colour of a halo depends on two factors—(*a*) the radio-activity of the central inclusion, and (*b*) the age of the mineral in which it occurs. As the helium atoms accumulate in their spherical shells the colour gradually deepens. It is interesting and significant to notice that haloes are found only in fairly old rocks. Granites of Tertiary age are generally free from perceptible haloes, whereas in biotite granites of Permian and Devonian age they are frequently well developed.

Some years ago Joly and Rutherford attempted to estimate the age of the biotite haloes in the Leinster Granite of Co. Carlow (Lower Devonian) by means of their colour. Artificial haloes were made in the same biotite under controlled conditions which made it possible to measure accurately both the *radio-activity* and the *time* for which it acted. Artificial haloes are made with a high degree of radio-activity acting for a short time. Natural haloes are made with a low degree of radio-activity acting for a long time. Suppose that a natural halo is found with exactly the same depth of colour as an artificial one. If now the radio-activity of the central inclusion can be estimated, then the *time* for which it must have acted can easily be calculated. The period of time so found would, of course, be a measure of the age of the halo, and of the mineral in which it had developed. Once the natural halo has been matched in colour with an artificial halo, the only problem that remains is the estimation of the radio-activity of the zircon at the centre of the natural halo.

The volume of the inclusion can be determined by working with a high-power microscope. Unfortunately it is impossible to separate the zircons and measure their uranium contents directly. The difficulty is surmounted by an appeal to probable limits. No zircons are known to contain more than 10 per cent. of uranium. If this figure is employed throughout for all the haloes examined, some of them, the paler ones, will give ages that are obviously too low; while others, the darker ones, will give ages that approach the correct figure, and may perhaps even exceed it. The values actually arrived at by Joly and Rutherford varied between 50 and 470 million years, the larger figure being certainly nearer the truth than the smaller one. Whether it is too high or too low cannot as yet be determined by the method of attack pursued in this investigation.

In the course of his continued researches on pleochroic haloes, Joly found that the uranium halo has a greater radius in micas from older granites than in those from younger rocks. The final results of his carefully confirmed measurements are these:

Source of Mica.	*Radius of Halo in millimetres.*	*Geological Age.*
Mourne Mts., Ireland	0·0136	Tertiary.
Ballyellen, Ireland ...	0·0146	Devonian.
Rapakivi, Finland ...	0·0152	Late Pre-Cambrian.
Arendal, Norway ...	0·0155	Middle Pre-Cambrian.
Ytterby, Sweden ...	0·0160	

Since there is a definite relation between the rate of disintegration of an atom and the range of the alpha-particles it emits, Joly considers it probable that uranium or some part of it decayed more rapidly in the past than it does now, and that the rate, and consequently the radius of the resulting haloes, has gradually decreased through geological time. Thorium haloes reveal no variation of radius with age, and this points to some unique complication in the uranium series that is not shared by the thorium series. Further, it proves in the only way yet possible that the rate of disintegration of thorium has not varied during geological time. An alternative explanation of the uranium anomaly would thus clear the way towards using uranium haloes as evidence that the rate of disintegration of uranium has also been uniform, or practically uniform.

Joly's explanation is rendered improbable by the consideration that if an unknown isotope of uranium had been wearing out through geological time, then in minerals it should now be largely represented by lead having an atomic weight different from 206. Moreover, some thorium minerals which have escaped alteration give the same lead-ratios as uranium minerals. If, therefore, the rate of disintegration of thorium has not varied in the past, it follows equally that the rate of decay of uranium must have remained substantially constant.

Uranium differs from thorium in giving rise to two distinct series of daughter elements, one of them proceeding by way of radium (97 per cent.) and the other by way of actinium (3 per cent.). It seems probable that the apparent anomaly in the uranium haloes is to be explained by an additional halo due to a member of the actinium series. In young haloes the effects would not be detectable at all, and the subsidiary halo would only become gradually visible to its maximum radius after a very long period. The apparent radii of " uranium " haloes would therefore increase from younger to older examples. Until the relations of actinium to uranium are made clear this alternative explanation cannot be proved, but it is at least in accord with the atomic weight evidence, whereas Joly's contention that uranium has disintegrated much more rapidly in the past is definitely out of harmony with all other evidence.

Another aspect of the question of constancy of rate of decay remains to be mentioned. No physical or chemical conditions that can be imposed on radio-active substances affect their behaviour in the slightest detectable degree. Speaking at the 1921 Meeting of the British Association, Lord Rayleigh summed up the situation when he said: " It is certain that nothing we can do in a laboratory in the way of change of temperature or pressure can alter the rate sensibly, and enough has been done in this way to make it unlikely that any pressures and temperatures encountered in the superficial parts of the earth could have such an effect. . . . Upon the whole, therefore, it would seem that in the disintegration of uranium we have a process the rate of which can be relied upon to have been the same in the past as we now observe it to be."

Finally, then, we may conclude that the age of an unaltered primary mineral is given *to the right order* by the formula—

$$\frac{\mathrm{Pb}}{\mathrm{U}+0\cdot38\,\mathrm{Th}} \times 7{,}400 \text{ million years.}$$

Taking into consideration the decay of uranium and thorium that has occurred since the mineral crystallised has the effect of reducing the age given by this formula. The corrected age can be most conveniently obtained by multiplying the approximate age by the expression—

$$\left(1 - \frac{x}{2} + \frac{x^2}{3}\right);\ \text{where } x = 1\cdot155\cdot\frac{\mathrm{Pb}}{\mathrm{U}+0\cdot38\,\mathrm{Th}}$$

The reduction involved is small in the later periods but rises to as much as 10 per cent. in the older Pre-Cambrian.

The table that concludes this chapter gives a summary of most of the data at present available. The next few years are likely to see a very considerable advance in the subject, as many American geologists, physicists, and chemists are now enthusiastically co-operating in the study of radio-active minerals, the National Research Council of the United States having appointed a committee on the Measurement of Geological Age by Atomic Disintegration under the able chairmanship of Professor A. C. Lane.

Although at present the geological age of many radio-active minerals is far from satisfactorily known, the calculated ages are everywhere in accordance with such evidence as is available. The beginning of the Tertiary dates back some 60 million years; the Upper Palæozoic, from the Devonian to the Permian, covers the range from 205 to 375 million years; the Pre-Cambrian reveals a set of results grouped about the three points, 600, 900, and 1050 million years, with one not very well-established age of 1260 million years lying beyond. Other minerals from Mozambique and Dakota have given still higher ages, but their testimony is not considered to be of serious value.

We seem now to have reached nearly the beginning of the earth's history, but even before the oldest known igneous rocks of any of the continents ascended from the depths there were sediments already formed at the surface in vast thicknesses, and these in turn must have been derived from the denudation of still older igneous rocks of which no trace remains. We may therefore add at least the length of an era to the greatest age determined from radio-active minerals, and say with confidence that the age of the earth is not likely to be less than 1,600 million years.

An attempt to find an upper limit to the age of the earth was made by Professor H. N. Russell on the assumption that all the lead of igneous rocks was of radio-active origin. Let us consider the quantities of the elements concerned in a million grams of average rock. Lead amounts to 7·5 grams; uranium to 6 grams and thorium to 15 grams. Expressing the radio-elements in terms of uranium alone—from the lead-generating point of view—the amount is U + 0·38 Th—that is, 11·7 grams. If all the lead came from the radio-elements (together with the corresponding amount of helium), then the original amount of equivalent uranium must have been 20·3 grams. Now the time required for 20·3 grams of uranium to disintegrate into 7·5 grams of lead and 1·1 grams of helium, leaving 11·7 grams of uranium, is just over 3,000 million years. The age of the earth cannot exceed this figure, because some of the lead in rocks may be ordinary lead of atomic weight 207·2, and because the radio-active elements may have existed in the sun and have there generated lead before the earth was born. We should therefore expect the age of the earth to be nearer 1,600 million years than 3,000 million years.

Lead-Ratios and Calculated Ages of Radio-Active Minerals

Minerals and Geological Ages.	*Lead-Radios.*	*Calculated Ages.*
Tertiary:		
1. Brannerite, Idaho, U.S.A. (*late Oligocene*)	0·005	35 m.y.
2. Pitchblende, Gilpin Co., Colorado, U.S.A. (*late Cretaceous or Early Eocene*)	0·008	60 m.y.
Palæozoic:		
3. Pitchblende, Joachimsthal (*Permo-Carboniferous*) ...	0·028	205 m.y.
4. Pitchblende, Cornwall (*Permo-Carboniferous*) ...	about 0·03	about 220 m.y.
5. Uraninite, N. Carolina, U.S.A. (*late Palæozoic*)	0·033	240 m.y.
6. Allanite, Blueberry Mt., near Boston, U.S.A. (*late Palæozoic*)	less than 0·043	less than 300 m.y.
7. Uraninites, Glastonbury, Connecticut, U.S.A. (*Devonian to Permian*)	0·039	290 m.y.
8. Various Minerals, Brevig, S. Norway (*? Middle Devonian*)	0·04	300 m.y.
9. Uraninites, Branchville, Connecticut, U.S.A. (*Ordovician to Permian, probably Devonian*) ...	0·052	375 m.y.
10. Coracite, Lake Superior (*unknown*)	0·062	440 m.y.
? Late Pre-Cambrian:		
11. Pitchblende, Katanga (*Pre-Devonian*)	0·081	575 m.y.
12. Thorianites, Ceylon ...	0·083	585 m.y.
13. Polycrase, Brazil	0·084	590 m.y.
14. Uraninite, Morogoro, Tanganyika Territory...	0·091	640 m.y.

Minerals and Geological Ages.	*Lead-Ratios.*	*Calculated Ages.*
MIDDLE PRE-CAMBRIAN :		
15. Bröggerites, Moss, S. Norway	0·125 to 0·135	900 m.y.
16. Cleveite etc., Arendal, S. Norway	0·145 to 0·165	1055 m.y.
17. Pitchblende, Sin[illegible]r, India.	0·13	900 m.y.
18. Monazite, Normanville, South Australia	0·12	840 m.y.
19. Radio-active Ore, Olary, South Australia	about 0·14	about 960 m.y.
20. Uraninites, Ontario, Canada	0·15	1020 m.y.
21. Samarskite, Douglas Co., Colorado, U.S.A. ...	0·15	1020 m.y.
22. Uraninites, Llano Co., Texas, U.S.A.	0·16	1080 m.y.
LOWER PRE-CAMBRIAN :		
23. Mackintoshite etc., Wodgina, W. Australia ...	0·187	1260 m.y.

Notes on the Table

3. The atomic weight of lead from Joachimsthal pitchblende is 206·4 (Honigschmid), indicating that only two-thirds of the lead present in the mineral is uranium-lead. The uncorrected ratio of 0·042 is thus reduced to 0·028.

4. The uncorrected ratio from an analysis of a selected specimen by Dr. N. F. Harwood is 0·047. The atomic weight of lead from impure material is 206·86 (Richards and Lembert). The true ratio is therefore between 0·047 and 0·014, giving 0·03 as a mean value.

5. The atomic weight of lead is here 206·4 (Richards and Lembert). The average ratio of 0·05 is thus reduced to 0·033.

6. From an analysis by H. V. Ellsworth in which the percentage of lead is known to be too high.

8. This is an unsatisfactory series, as many of the minerals are rich in thorium and appear to have lost a great deal of their thorium-lead. It is also possible that the age is Lower Carboniferous.

10. The age of this mineral is probably late Pre-Cambrian or Ordovician. Unfortunately, its locality is no longer known.

11. The atomic weight of lead is 206·048 (Hönigschmid and Birckenbach), showing it to be nearly pure uranium-lead. For note on age, see 14.

12. The ratio given here is that of analysis No. 2 as calculated from the amount of uranium-lead indicated by Hönigschmid's atomic weight determination (page 64).

14. The atomic weight of the lead is 206·04 (Hönigschmid and St. Horovitz). The geological relations of the rocks in which the minerals 11—14 occur all suggest that they belong to the late Pre-Cambrian revolution and its attendant igneous phenomena. An early Palæozoic age is not ruled out, but is not supported by comparison with the geological history of other better known regions.

15. The atomic weight of the lead is 206·06 (Hönigschmid and St. Horovitz). Middle Pre-Cambrian time includes two eras separated by revolutions from the preceding and succeeding eras. There is therefore room for a wide range of lead-ratios in the series 15—22. Thus series 15 may represent the revolution at the close of Middle Pre-Cambrian time, and series 16 that separating the two eras.

18. This result is probably low, as the mineral contains thorium and practically no uranium.

19. The uncorrected ratio is 0·2, but the atomic weight of lead from the ore is 206·34 (Richards). If the analysed material was selected for its purity, then the ratio may be higher than 0·14. Geologically 18 and 19 appear to correspond respectively with 15 and 16 of Norway.

23. This group of minerals occurs in the Warrawoona series, stated by Sir Edgeworth David to be probably the oldest of the three divisions of Australian Pre-Cambrian rocks.

CHAPTER VII

THE CONVERGENCE OF EVIDENCE

"The mountainous ages made hoary with snows for the spirit to climb."—SWINBURNE.

WE have now passed in review the various methods that have been devised to measure geological time, and, if possible, to ascertain the age of the earth. The results are of very different orders of value, and only those based on the reading of the radio-active timekeepers of the rocks make any pretension to either precision or accuracy. Nevertheless, the results, such as they are, afford one another a very considerable degree of support from the fact that there no longer remains any outstanding discrepancy. The various conclusions we have reached are as follows:

The Age of the Earth as a Planet:

(*a*) From the eccentricity of the orbit of Mercury—between 1,000 and 5,000 m.y.

(*b*) From the tidal theory of the origin of the Moon—less than 5,000 m.y.

(*c*) From the journey of the Solar System from the Milky Way—between 2,000 and 3,000 m.y.

(*d*) From the average quantities of lead and radio-active elements in the rocks of the earth's crust—less than 3,000 m.y.

(*e*) From the oldest analysed radio-active minerals—greater than 1,400 m.y.

(*f*) From the accumulation of salt in the oceans—greater than *n* × 330 m.y. (where *n* is a multiplier such as 5).

(*g*) From the thickness of the geological formations—incalculable.

(*h*) From the conception of cycles and revolutions in the earth's history—over 1,400 m.y.

All the evidence is consistently in harmony with the conclusion of the last chapter that the age of the earth is between 1,600 and 3,000 million years. If an estimate like that of (*c*) could be relied upon, the range would be narrowed down to 1,600 and 2,000 million years. At present however, there is no real justification for making this limitation, for estimate (*c*) is the least valuable of all, since it is based on the flimsy basis of a plausible guess. The more scientific procedure here would be to argue from the results of (*d*) and (*e*) that the Solar System probably originated in the Milky Way.

In the detailed measurement of geological time, period by period, only the radio-active and geological methods remain in the field. When the radio-active evidence first appeared geologists still felt seriously cramped for time because of the definite boundary which their great antagonist, Kelvin, had set to the age of the earth and the sun. A mere twenty million years was of little more use than the few thousand years of Archbishop Ussher. Again the tide turned, and the old controversy was settled overwhelmingly in favour of the geologists who wished for longer periods. But certain geologists, like Professor Sollas in England and Dr. Walcott in America, had already tried to squeeze geological history into a few million years. Their work had a wide influence, and when the enormous periods revealed by radio-active minerals were announced, it was felt by many that they were excessive and a source of embarrassment. There was general anxiety lest the results of the radio-active method should prove to be as much too high as Kelvin's were too low.

In both geological and radio-active calculations the chief assumption is that of uniformity of rate. We have carefully examined the evidence in this little book—perhaps to the point of boredom—for on the decision arrived at depends the solution of any discrepancies that may still be thought to remain. Ample evidence has been found in the geological record of cyclic rather than uniform changes; ample evidence that present rates are abnormally high, and that the older estimates of geological time were far too low. On the other hand there is no reason for doubting the straightforward evidence of uranium minerals, and there is visible record in the rocks themselves that the atoms in the earth's earliest ages behaved in exactly the same way as those of to-day.

That the discrepancies have gone, and that geological and radio-active researches may now proceed together in complete accord is made clear by the following table—

GEOLOGICAL CYCLES, EACH TAKEN AT 30 MILLION YEARS.	AGES IN MILLIONS OF YEARS.		
	By adding successive Cycles	From Radio Active Minerals.	
0. Present Day	0		
1. Upper Tertiary	30	35	
2. Lower Tertiary	60	60	
3. Upper Cretaceous	90		
4. Lower Cretaceous	120		
5. Jurassic	150		
6. Triassic	180		
7. Permo-Triassic	210	205	375
8. Permo-Carboniferous	240	220	
9. Upper Carboniferous	270	240	290
10. Lower Carboniferous (*b*)	300		
11. Lower Carboniferous (*a*)	330		
12. Upper Devonian	360	300	
13. Middle Devonian	390		
14. Lower Devonian	420		
15. Silurian	450		
16. Upper Ordovician	480	440 (?)	
17. Middle Ordovician	510		
18. Lower Ordovician	540		
19. Upper Cambrian	570		
20. Lower Cambrian	600		
Late Pre-Cambrian		575 590 640	

In this the twenty cycles of Chapter V. are listed and to each is allotted the duration of 30 million years which was found from geological evidence to be characteristic of each of the first three. Side by side with the geological time-scale so constituted the dates read from radio-active minerals are placed as closely as possible in their proper places. When only a range of period is known it is indicated by a bracket. The general agreement is remarkable, and this convergence of evidence is of fundamental importance, since it shows that the whole question is at last in a fair way towards settlement by general agreement.

Several geological writers have expressed their considered opinions of the relative lengths of the Palæozoic, Mesozoic, and Cainozoic eras. These are listed below, and it will be seen that the average of the estimates is almost identical with the relative lengths as determined by the number of cycles. It is worth noticing that if we define an era as the interval between the successive revolutions marked by large-scale mountain building, then the Palæozoic is really two eras, and the Cainozoic is merely the revolutionary part of a single Cainozoic-Mesozoic era.

Ratios of Era Durations (Relative)

Author.	*Cainozoic.*	*Mesozoic.*	*Palæozoic.*
Dana, 1874 -	2	6	24
Walcott, 1893 -	2	5	12
Goodchild, 1896 -	2	4·2	9
Schuchert, 1914 -	2	4·8	11·2
Barrell, 1917 -	2	5	13
Average ratio -	2	5	14
No. of cycles -	2	5	13

As far back as the Cambrian the time-scale is becoming detailed and increasingly reliable. Beyond, the geological record has as yet made possible little more than a hesitating era classification. The finer division into cycles is a task for the future, and as a means for guidance geologists in every continent are searching for the radio-active minerals which alone will enable positions to be fixed and correlations to be made. At present the fixed points are neither numerous enough nor sufficiently well defined to permit more than the broadest correlations from one country to another.

With the gradual development of a reliable time-scale geology is gaining an invaluable key to further discovery. It is only now that man, as Swinburne expressed it, can begin to "see through the years flowing round him, the law lying under the years." Given a standard scale of time the leisurely progress of evolution can be measured. Variations of climate, of volcanic activity, of mountain building and of life can be set down in their proper order in a well-proportioned scheme of years. Our place in the eternal miracle of existence is becoming more closely defined, but though a veil is lifted a greater mystery remains behind. Beyond the earth, receding into an inconceivable remoteness, lies the stellar universe, the stage in which the drama of our earth is set. Here another veil is lifting, for Nature, no longer taciturn when approached in the right spirit, is slowly but surely yielding up her secrets. The nature of the evolution of the stars and the hidden sources of their blazing energy are being revealed; and we are adventuring towards the very threshold of Creation—towards the birth-time of the universe itself. Yet in another sense we are there already, for, transcending the majestic cycle now running its course, there is still no sign of either beginning or ending, and with Alfred Noyes we can declare:

"Here, now, the eternal miracle is renewed;
Now and forever God makes heaven and earth."

MONKSEATON,
NORTHUMBERLAND,
August, 1926.

AN INTRODUCTION TO GEOGRAPHY

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AN INTRODUCTION TO GEOGRAPHY

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LONDON: ERNEST BENN LIMITED
BOUVERIE HOUSE, FLEET ST. E.C.

First published 1929

MADE AND PRINTED IN GREAT BRITAIN BY
BILLING AND SONS, LTD., GUILDFORD AND ESHER

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The writer wishes to thank his friends, Mr. E. G. Bowen, Mr. C. C. Carter, and Dr. J. H. Shaxby, for much help in preparing this little book.

AN INTRODUCTION TO GEOGRAPHY

CHAPTER I

INTRODUCTION

Geography as a study is one of the most definite outcomes of the desire, and the need, which men feel for a vision of the world around them, a need both for guidance in action and for investigation of truth. As this need has existed from the dawn of civilisation onwards, geography is one of the oldest of the sciences, and it has usually been concerned with the piecing together of knowledge of many different kinds. In a sense most of the specialised sciences can be considered as offshoots of geography, and there is thus a widespread overlap between geographical and other studies, and the delimitation of the province of geography is unprofitable. It would be too long a task to attempt to trace the modifications of the conception of geography from the earliest times of which we have any knowledge, but it will help forward the understanding of the modern position if a short reference is made to some of the more recent phases of its transformations—that is, to some of the results of changes in men's visions of the world.

A mediæval Mappa Mundi is a most interesting document, not from the point of view of degree of correctness, necessarily low, but for the sake of its indication of a vision of an earth centred around Jerusalem, itself conceived as lying immediately below the throne of the Deity. A geography of phantasy and prejudice naturally accompanied this view of the world. Maps and geography on these lines were swept away by the discoveries of Copernicus and the voyages of the Renaissance. Now arose the geography so specially represented by the Royal Geographical Society of London with its emphasis on exploration of distant lands and the accompanying development of methods of surveying and cartography as part of the task of at least some geographers. With the rise of mass production and steam communication and the contemporary development of modern science there naturally arose two other trees of geographical knowledge. Modern science, physics, chemistry, geology, and biology led men to have enlarged visions of chains of causation in natural phenomena and so to the study of the earth's surface, called by Huxley physiography, and by others physical geography. Mass production and its philosophy as embodied in the doctrines of the Manchester School of Political Economy found their expression in some of the older economic geographies in which, after some enumeration of physical features, attention was concentrated upon economic products and the centres connected therewith. Needless to say, the improvement of the first of these two types of geography brought it nearer and nearer to geology, while the improvement of the second, and the increasing realisation that the present is only a plane of infinite thinness separating the past from the future, brought it nearer to history.

The actual state of affairs may be summed up by saying that at least the primary exploration of the major features of the earth's surface is now far advanced and the methods of surveying and cartography have been carried to a high grade of accuracy. In both these fields the work of the future is likely to be in the direction of increased detail of exploration, and detailed application of perfected surveying methods to larger and larger parts of the earth. And, for increased detail of exploration, there is need of a vision of the whole, or essentials will be missed, while for the spread of mapping over the world there is also need of vision of the whole lest we exclude from our maps just what men will need.

Yet, in spite of this, the structure achieved by some generations past has seemed to be undergoing a deep fission into two incomplete and inadequate ones, the physical and the historic, and we are in some danger of falling into the fallacy against which General Smuts so earnestly warns us in *Holism*, the fallacy of thinking that, having split the whole, in our minds, into parts, we can next take the parts, as our minds conceive them, try to stick them together and so have the whole once more.

All the while, however, the progress both of science and of economic thought is developing a clamorous need of a new outlook. Darwin made men see the unity and order of animate nature, and his method and principles are penetrating into the study of the innermost dreams of men's minds, to their great illumination and redemption. Everywhere life and environment are seen reacting one upon the other, and the story of life is largely a story of a persistent, and, on the whole, successful effort for increased opportunities in each environment. In parallel fashion the progress of economic thought has, as it were, justified Blake, Dickens, and Shaftesbury rather than the Manchester School. The person is seen to matter after all, and there is a marked progress in industrial psychology and economics towards thinking of men in their struggle with environmental problems and towards making that struggle one which will be more the activity of a unified personality, and less the modification of men into machine-tenders.

The study, then, of men in their environments, with the thought that both men and environments are changing as the generations pass, is a great need arising out of the problems of the day, and out of the modern scientific progress. It contrasts rather sharply with the study of man in the abstract, which was one of the most valuable products of the Renaissance. We must study, not only man, but men, in all their diversities, differences related to differences of history in varied environments, and, not only the earth, but its diverse regions with their diverse opportunities and difficulties.

If we confine our attention to the present time, to the infinitely thin screen between the past and the future, we have merely static descriptions, always out of date, because the screen moves inexorably on. Such descriptions, in summary form, are invaluable as a gazetteer, but can hardly claim to be a fully developed science. For that we need to see, not only the present, but its evolution; we need a sister study to history: side by side with the ascertainment of the order of events we must follow the changing interactions between man and environment as best we can. French scientific workers have recently shown that they have caught something of the idea, for they have developed a series of books entitled *L'Évolution de l'Humanité*. That is one possible description of the task, but not a full one, because it tends to lose sight of the environment that changes with the changes of life. Another description that has been suggested is that of the "Study of the Influence of Geographical Environment," a branch of study that owes a great debt to Friedrich Ratzel, but a branch that is ever in the gravest danger of growing into deformed shapes, because its students are apt to forget that forms of life influence their environment in myriad ways, and some have even acquired more than a little power of selecting their environment.

Exploration, surveying, and cartography, evolution of the earth's surface, climate study, including that of the climates of, at any rate, the human past, and the relations of plant, animal, and human life to their environments, studied from an evolutionary point of view, are all needed to help to make the picture of Man and the World. It is well if those who try to be geographers are specialists in one or more of the contributory branches of study, so it is natural that there should be differences in geographical research as regards the placing of emphasis. At the same time, one of the main tasks for all is that of picturing the earth and its regions in their relation with human life. The evolutionary description of a region is thus one of the chief objects of geographical work, and one which is of a synthetic character, calling for personal knowledge and a highly developed sense of perspective and balance. The geographer cannot understand the surface of Scandinavia, the climate of Central Asia, the characters of the Congo Forest, the distribution of hoofed animals, the characteristics of human races, or the features of villages, cities, transport, and industry, without digging deep into the past. Nevertheless, if he be a geographer he will study the past for the sake of the present; he is less a chronicler or recorder than a student trying to illuminate the present by an interpretation built upon an appreciation of its evolution.

Enough has now been said to show that the complex development of thought has brought to birth a number of studies which are all fairly closely related and are not by any means mutually exclusive. They have arisen from different movements of thought and action, and are too important, too vital, to be crushed into a frame of logical subdivisions of the development of modern thinking. Among geographical studies, as developments of scientific inquiry that have arisen in the course of time, we may claim place for the following branches, and liberate ourselves from the rather useless dilemma about dividing this, or any other, subject in a purely logical fashion.

1. *Exploration, Surveying, Cartography.*—This is in

a sense fundamental, for the map is the geographer's special instrument, and its perfection is, therefore, one of his special aims. The Royal Geographical Society of London stands in a very special sense for the fulfilment of this task from which the remaining divisions naturally spring.

2. Efforts and experiments towards the improvement of maps, not only from the point of view of correctness of the basic surveys, but also from the point of view of their value as pictures of particular aspects of the environment that man has either found or made. Thus the meteorologists have improved maps of climatic facts, while many students of distributions of phenomena and objects have elaborated schemes for depicting such distributions.

3. The study of distributions of all kinds in their relations with one another, and especially of cultural distributions in their relation to distributions of climatic, orographic, botanical, and other features. The opportunity is ever present to look behind the distributions into their causes, and for such study it is especially important for the geographer to have knowledge in the related fields of study involved.

4. The study of regions, using data from the first and third divisions above, to build up a valid and valuable picture of a region, and especially of the life of men within the region, as a product of evolution there and elsewhere. The direction of emphasis will depend on the interests and skill of the student.

5. The study of interrelations between regions, or of changes of distribution with time—in other words, so far as human affairs are concerned, the movements of culture, using this term in the broadest sense.

6. The utilisation of all these studies for deepening comprehension of the relation of man to the earth, and for helping towards a philosophical survey of human society.

It is sometimes said that the above topics, being closely bound up with mathematics, physics, geology, biology, anthropology, history, and economics, in different cases, cannot be brought into geography, and that their geographical aspects come best under the special analytical studies concerned in each case. The actual fact is that many of them have limited their own growth through want of appreciation of such arguments and interpretations as the geographical point of view would develop. Truth has so many approaches that each of us can follow but a few in the course of a lifetime of work, and the recognition of many different outlooks as supplementary rather than contradictory would lead to immense advances in knowledge, and especially in understanding.

Vidal de la Blache urged repeatedly that, while geography is helped by many of the special sciences, it can repay its debt by maintaining the need for looking at things as wholes, by helping to guard against the danger *de morceler ce que la nature rassemble*. The whole is usually more than the sum of its parts; as a whole it has functions and relations which may not be functions or relations attached to any of its parts. General Smuts's recent book, *Holism*, deals with this idea and emphasises the need for increased attention to wholes. It is admitted that geography is still at an early stage of the development of its method and technique in this field.

CHAPTER II

THE GEOGRAPHY OF THE EXPLORER

The spirit of the child is the quickening element in many an activity of adult life, and in few does it work with the same power and attraction as in "going truly exploring." In our own time the exploration of the Polar Regions, the climbing of Everest, the mapping of the interior of New Guinea, and the investigation of the depths of the sea have all provided many topics for discussion, and, at any rate, nearly all of them have done much to add to knowledge, even to add to human opportunity. The primary or general exploration of the earth's surface is now nearly done and that of the sea is well advanced, but there are endless details to be corrected or filled in, such as, in recent years, the details of the course of the Brahmaputra as it breaks through from Tibet to Assam, or the details of orography between the Nile and Lake Chad. Some maps are still somewhat precarious generalisations on the basis of a few observations probably made at great cost of effort under heavy difficulties; but a general notion of almost every part of the world, in so far as this concerns height of its features above sea level or their depth below it, is available henceforth.

Not only is this achieved, but by much discussion a very considerable accuracy has been attained in the depicting of the forms of the earth's surface, both above and below water, on maps, so that wherever improved data are got by an explorer with the latest patterns of instruments there is confidence that they will be recorded in a satisfactory way.

The surveyor's and the cartographer's art have advanced far, and the explorer's work has all but reached the end of its first chapter. What of the future?

The explorer, equipped with biological, geological, and anthropological knowledge, has not only the greatest of opportunities, but if he be a biologist or anthropologist, the most urgent of calls. One after another of the beasts of olden time becomes as extinct as the dodo, and the danger of extinction seems to threaten more than a few human groups; it has already overwhelmed the Tasmanians. It may be urged by the "practical" person that this matters very little as the extinct forms were clearly poor creatures. This last contention of the poverty of the extinct forms may even be granted, to avoid argument rather than to pronounce agreement, and yet there remain reasons of great importance, at least for delaying the complete extinction of interesting and peculiar types of plants, animals, men, and societies. It is a very great hindrance to the study of man and of his societies that we know so little, and can now never hope to know more, of the Tasmanians. The deterioration and threatened extinction of Andamanese and others is an alarming fact; we have some detailed accounts of several such curious survivals of a far-off past of humanity, but we never know when we may not need to investigate some new point hitherto unappreciated, and, moreover, we still have reason, in more than a few cases, to doubt whether a transplanted stock will really take the place of a more definitely indigenous one. Of course this transplantation process has demonstrated its success in some cases, not seldom, however, by a process of blending.

One fascinating element in exploration with a biological point of view in these days is that the explorer's record, if thoughtful enough, is likely to remain as an established work and not to be merged in the anonymous stream of knowledge as is the case with most scientific work. Knowledge of Africa may have gone far beyond Mungo Park or Livingstone, yet their

Africa no longer exists, and their work is thus classic and monumental. Again, what can supersede C. M. Doughty's *Arabia Deserta,* or H. W. Bates's *Naturalist on the Amazons,* or von Richthofen's *China?* They picture conditions, elements of which cannot but pass away; their work cannot grow out of date and its value may rise enormously as the changes of time accelerate. Those who, like Doughty and Bates, have the gifts and the patience not only to observe truly and analyse deeply, but to picture with clear conscience added to artistic vision, are among the leaders of the advance of knowledge, and are little likely to be washed over by the waves of oblivion. There is always work of that kind to be done and help and recognition for it when it is done, but it is work that needs both specialist preparation of more than one kind and a general appreciation of many aspects of both science and art; it is, at its best, work for a small elect element; it is also work that will probably never come to an end in spite of all the modern influences towards world-uniformity.

The student of geography is, then, well advised to include in his purview a good selection of the works of great explorers of the poles and the mountains, the air and the sea, the flowers and beasts of the field, and the ways of men of many lands. He may learn the wonder of the world, he may even awaken the power within himself to become an explorer in the great succession from Eve, the pioneer of that search outside the limits of habit, which is often hampered by prejudice and misunderstanding.

Not only is the field of exploration waiting with endless opportunities for genius, but it has also been providing thrills of late through applications of new methods. The aeroplane is the most striking of many examples here, and we may think at once of those who have had the new experience of flying over the tops of the great equatorial forests, getting a new view that may be able to tell us of biological and other relations we little suspected or understood. But it is not only in the exploration of unknown distant lands that the aeroplane has come to help the explorer. With an aeroplane and a camera many parts of the earth have been photographed from a fresh point of view, and sometimes maps have been corrected thereby, even as regards the plain facts of relief. One other result of air photography, a romance of modern science, is specially connected with the British Air Force and with the name of Mr. O. G. S. Crawford, the Archæological Officer of the British Ordnance Survey. It is found that differences hardly perceptible to the eye stand out in air photographs, differences, for example, in the greens of crops according to the soils in which they grow. In this way, in many cases in which even the most complete and conscientious work with pick and shovel on the earth's surface would have revealed very little, air photography has given clues that have led to the discovery of hitherto unsuspected vestiges of the past even in such a minutely studied region as the Salisbury Downs. There is explorer's work to be done in many a well-known neighbourhood with the help of air photography and other devices of science, and the work will contribute new and valued knowledge.

CHAPTER III

THE MAP

THE mediæval Mappæ Mundi have been left far behind, but the play of fancy long survived them, for our older cartographers, long enough after the Renaissance, still filled in unexplored regions with pictures of strange beasts and inscriptions of vivid, if at times hardly scientific, interest. The spread of the scientific conscience and the progress of exploration has threatened the extinction of this pictorial element of the old map. There is now so much to put in that fancy gets little scope to play. From the old pictorial map the pendulum swung all too far to maps merely crowded with names, the most dire success in this field being probably that attained in the maps of states of the United States of America in the eleventh edition of the *Encyclopædia Britannica*. The artistic spirit must help the scientific understanding to give a better result, and the historical study of the representation of relief, of physical features, of centres of population, and so on, is a fascinating side track of the geographical road.

The early experiments of the British Ordnance Survey, and especially of Colby, have led ultimately, with improved methods of finding altitude, to the use of both hillshading and contouring to picture slopes on fairly large scale maps, and to the idea of piling up layers of colour in imitation, as it were, of the layers of which the earth, for this purpose only, may be supposed to be built.

The vicissitudes of the fight between richness of reference and so-called economy in our Ordnance Survey and in other schemes of large scale mapping are an interesting, if at times depressing, story. The progress of such surveys suggests a possibility, already realised here and there, and notably in Egypt, of making the survey cadastral—that is, a term of reference in matters concerning boundaries of landholdings. Such an advance as this would, indeed, justify geography in the eyes of many a man of affairs, if governments could but give the required lead and trust to indirect recoupment from probable simplification of business transactions and legal processes. A tribute must be offered to the value and beauty of many of the ordnance maps of the British authorities, and the one-inch tourist map of Killarney may be specially mentioned.

The spread of the historic sense has led to a widely diffused interest in old maps. This, on the one hand, has brought with it the perverted notion of sacrificing documents of, at times, unique value for merely temporary decorative purposes; but, on the other hand, it has led artistic craftsmen to take up afresh the old cartographical ideas of cloud-capped towers and magic casements, and to make maps, for example, of historic cities that are expressive in a way the "flat map," common till recently, cannot emulate. There is a future for the revived old map executed with artistic feeling allied to scientific care, not only for those whose interest is æsthetic, but also for geographical education, which is continuously faced with difficulties of the complex interweaving of many concepts, that lead the student into error if they are treated separately, and yet are too difficult to be kept in mind together unless the utmost help is given to the eye.

A welcome evidence of the increase of geographical appreciation in recent years has been the publication of maps with what has been called above lay-colouring, and the boundaries of states marked in lines on them. These are the successors of older maps with the states in variegated colours and the physical features subordinated or quite neglected. The change denotes a weakening of the old habit of state-worship and an increased grasp of the fact that a state is typically an organisation of people upon some particular piece of land with problems and relations arising from its situation and physical features. For demonstration at a distance the old type of political colouring may still be useful, though one current map-maker at least contrives to make the layer-colouring, with shading added, and the lined political boundary conspicuous enough for all practical purposes on one and the same map.

One of the most valuable geographical enterprises of this century has been the effort for a 1 : 1,000,000 map of the world on an internationally agreed basis. The scheme has met many difficulties: troubles about co-operation of surveying bodies with different schemes of work on the two sides of a frontier that may cross a sheet; troubles about great variations in the amount of detail put in by different surveys; and troubles about the insertion of layer tints, and so on. The measure of success attained by the scheme has been enough to show that this map is something that is needed and that must be achieved in the future: complete success of a first effort in a matter of such international complexity was not to be expected. Even the measure of success achieved has been enough to help geographical study by providing many maps of different regions in which scale, projection, colouring, and so on are uniform enough to allow the student-eye to proceed beyond these primary items to the subtler points which help to give the vital comparisons and contrasts between the regions under consideration.

Thus are maps being brought into relation with general world study by the 1 : 1,000,000 scheme; with the realities of the earth by the development of layer-colouring; and with increased intensity of understanding by the improvement of shading as a supplement to layer-colouring, and by the improved notation used to mark the different objects indicated on the map.

This century has seen, too, a great expansion of the mapping of distributions, whether by the use of lines to indicate positions along which something, be it average temperature, average rainfall, or average barometric pressure, maintains an approximately equal value, rising on one side and falling on the other in an ordinary case. Isotherms, isohyets, and isobars have attained a very widespread publicity both in research and in education, and they are all related in origin to the contour line, or line on a map representing points all at the same height above, or below, sea-level. Experiments have been made with indifferent success to use the same method in studying distribution of population, of crops, etc. These distributions, however, are far more irregular and discontinuous than those of atmospheric conditions, and in general the contour method fails here save for purposes of a very rough introductory notion.

For these and many other purposes cartographers have tried stippling, or the insertion of dots, on the map, corresponding in density, on some agreed scheme, with the density of people, crops, etc., to be mapped. The stippled map constructed on a sufficiently refined and yet bold scheme may tell its tale well, in broad outline, but when it comes to details there is trouble, as it is almost impossible to estimate what the stipple means by counting the dots in a certain area unless they are very close together, and then they are bewildering. A scheme of plotting the population by colouring is being experimented upon by Beckit and a committee of the Geographical Section of the British Association, so that areas of approximately uniform density, say of population, may be coloured uniformly regardless of the colouring of adjacent areas. This scheme, at its best, will give a curious patchwork without the neat gradations to which our eyes have become accustomed in layer-tinted maps, or maps showing isotherms, isobars, and isohyets, but it is the best plan as yet devised. These matters are mentioned to show how much geography has still to do to improve maps even after surveyors, geometers, and draughtsmen have done their best. The advance in the last twenty years has been phenomenal, and there seems little reason to doubt that a great further advance will take place in the next twenty.

A generation ago a historical map was apt to be crowded with names relating to the whole history of a region from the earliest times, and historical geography was apt to consist mainly of an attempt to learn where, on a map almost without physical features, places mentioned incidentally in a chronicle happened to be. Scandinavian, German, and French scholars have led a great advance whereby a historical map increasingly tends to give a representation of the conditions of a specified period, and the places named or the distributions marked are usually such as are related to that period. It may be permissible to mention specially Dr. C. Fox's maps in his *Archæology of the Cambridge Region* as an interesting advanced experiment in that direction, and the British Ordnance Survey's maps of Roman England and Wales, and of England and Wales in the Civil War (Dr. J. E. Morris' data) are welcome indications of policy. At any rate, historical maps are outgrowing the stage at which they showed only a jumble of names and changes of colouring due to changes in outlines of states effected by wars and treaties and dynastic bargains. This shows the change of mind that has diminished the prestige of states and increased the interest in peoples and their problems.

There is no doubt that the war crisis of 1914-1918 and the wide realisation that victors and vanquished suffer together has forced forward the plea for better small-scale and atlas maps, for more accurate and intensive picturing of environmental conditions. In the same way, practical experience of the motorist and the aeronautist, as well as of the general staffs of armies, has led to increased interest in improvement of the moderate scale maps, and practical needs of town and country planning are leading to the need for the best possible large-scale maps. As always, geographical studies and their instruments are linked up in intimate ways with practical life, and depend upon it at many turns for stimulus, however purely scientific the actual method of work and the object to be achieved may be.

Mathematical study long ago settled some main lines of the schemes for representation of regions on flat maps—that is, settled several types of map projections, each aiming at accuracy in a particular direction. More recently new experiments have been made in the direction of special projections to illustrate special points of geographical distribution, and a notable type here is that of interrupted projections now increasingly used in several forms so as to show world distributions with as little distortion of positions or of areas as is possible. It is characteristically the matter of projections for world-maps or maps of very large regions that is of special interest at the moment, and this is an understandable accompaniment of the efforts towards synthesis that are making themselves felt.

CHAPTER IV

THE STUDY OF DISTRIBUTION

THE study of distributions of phenomena and objects may be made very profitable if pursued far enough, but it is a topic which is difficult to develop in absence of illustrations. This difficulty partly accounts for the selection of subjects for treatment here and for the omission of others, such as those concerned with the distribution of certain economic cultural products, for a study of which the gradations between intense and sparse production are important.

The visitor from our North-West European countries to the Mediterranean notes, among many contrasts in vegetation, the striking diminution of the beech-tree that gives so much beauty to the British spring; it disappears towards the south in both Italy and Spain save for a few speciments on the cooler heights. The suggestion based upon this is that summer drought is a limiting factor for the beech, and this is supported by a study of the details of the limits of the beech in Spain, where it occurs on the north and north-west coasts and in the rainier parts of the Duero basin (Old Castile and Leon). It is still further borne out by a study of the eastern limit of the beech, a zone from the east of East Prussia to the vicinity of Odessa. On the Carpathians the beech is found at considerable heights, so severe winter cold is not a complete bar; beyond this general limit, to the south-east, on the other hand, summer heat and evaporation are very great. The beech appears, however, farther east near the Caucasus, where more moisture is available. The factors which determine its northern and north-eastern limit are less clear; it occurs in South Norway and in Sweden south of the great lakes, and Denmark is one of its most notable homes. Along this limit it seems that the tree has not to withstand such extreme winter cold as it often feels on high places in the Carpathians, so, here again, winter cold does not appear to be the limiting factor, and it is probable that returns of severe cold after the opening of buds in spring are of greater importance.

There is a certain relation, though not identity, between the limits of the beech and the limits of the *Humid Brown Earths* of Glinka's soil classification. They occur where rainfall, evaporation, and temperature are moderate, and so leaching is not carried to extremes; beyond their area towards the north-east evaporation is slower and ground waters leach the soil to a greater extent, so that it is greyer and is known as *Podsol* in Glinka's and other schemes. In Podsol areas the dissolved humus washes down into the deeper layers, which thus have a higher iron content than the upper layers. Beyond the area of humid brown earths to the south, strong evaporation and rapid chemical action under the strong sun quickly decompose humus and draw up moisture so that iron salts, becoming hydroxide, accumulate near the surface and make the soil reddish in many places unless drought is still greater, when under certain conditions it may be grey.

We thus have a certain relation between the region of the beech in Europe and the region of the humid brown earths, and both are related in extent and limits to the region for which mixed farming of cereals and stock, typically with a traditional rotation of utilisation of the soil, involving fallows, is older established than it is for the areas beyond it to the east and north-east. The same area is also that in which the idea of the nation state, in the first instance an agricultural nation state, grew up, and within its bounds are nearly all the parliaments of the old world which have withstood the severe testing time of the twentieth century, though the parliamentary system has been submerged or has failed to become established on its borders in Spain, Italy, and Yugoslavia, in Hungary, Rumania, Poland, Lithuania. How far all these facts and features which have closely similar distributions are related to one another it might be possible to argue at great length. Probably one would approach a wider truth in suggesting that they are all related to a mild oceanic climate in regions wherein the sea penetrates deeply and so gives possibilities of communication and exchange that, thanks to the mildness, can go on practically without interruption either by ice-impediments or by lowering of the vigour of the people through prolonged exposure to extremes of cold and heat.

As the traveller towards the Mediterranean watches the last beeches disappear he notices the first olive-trees in solemn grey-green garb, often on a reddish soil, and if the distribution of the beech makes it a sort of index-plant of the nation states of North-West Europe, the olive is still more the index-plant of Mediterranean civilisation. It appears not many miles north of Avignon and not many miles west of Narbonne, it avoids North-West Spain and flourishes most in the south, it favours peninsular Italy, but becomes scarce not far from the Rubicon as one goes north, and in the Po Basin is found only in specially favoured spots. It lives on the coast and avoids the interior of the Balkan peninsula and Asia Minor. It occurs in the coastal zone of French North Africa and in Cyrenaica (Barca). It is thus essentially bound up with Mediterranean conditions of relatively mild winters and warm summers, with a rainy season in autumn or winter, but not too fierce or too prolonged frosts.

This distribution on Mediterranean coastlands is the more interesting because much of it is due to men's efforts. The original home of the olive is a subject of speculation, but it was in all probability some region within the area of or in fairly close contact with the early civilisations of the Ægean basins. Its spread around the Mediterranean shores westwards helped materially to raise the level of economic life in the western basin of the Great Sea. It gave a source of food specially valuable in a region where cultivable flat areas are small and summer drought limits the amount of available pasture. Its products admitted of transportation even under the conditions of ancient times, and thus promoted trade. The olive orchards needed years to reach maturity, and the possession of them implied a longer perspective in their possessors than was often found in ancient times in lands farther north. That the olive contributed considerably to the growth of settled populations in the Mediterranean area is thus clear. Its essentially coastwise distribution was an added factor in the promotion of coastal, and especially harbour, cities as a special feature of Mediterranean civilisation, and such cities have as a fundamental and natural feature the possibility of intercourse, with all its potentialities for enrichment of life and prevention of fossilisation of society. Olive orchards gave some shade for other crops, and thus helped agriculture, which was generally committed to a small plough that could be worked around and among the trees.

The organisation of agricultural labour in an olive region was thus perhaps less complex than in an area of common fields, and labour was a less important consideration than possession. The owner might often live mainly in the city; sometimes the labourer might do so, too. Origins of Mediterranean society are far too complex to discuss here, but the position of agricultural labour on the one hand and of galley labour on the other, as contrasted with that of ownership of an estate yielding to a city dweller bread and olives and the products of distant lands, may be considered to be an important factor of its stratification. It is further an outstanding fact that the city in the Mediterranean area is far older than in Europe farther north. Hissarlik II., the earlier city on the site of the later Troy which the Greeks destroyed, dates back to about 2600 B.C., and Knossos, the capital of Minoan Crete, also attained wealth and influence in the third millennium B.C., whereas in Europe, away from the Mediterranean, cities do not begin effectively until the Romans introduce the idea. That is, there is a difference of two thousand five hundred years between the evolution of the city in Mediterranean lands and its evolution in Europe farther north, the region where the village of wheat growers is the fundamental unit.

As the olive vanishes and the Mediterranean is left behind, the southward traveller reaches the region where the date-palm lifts its magnificent blue-green crown of leaves and gold-brown fruit into the brilliant sunshine. Unlike almost all the other food-bearing palms, it lives not in the equatorial and subequatorial zone, but on the desert borders and in the desert oases. It probably originated somewhere in the desert zone, though a spiny, dry-fruited relative is known between the tropics. Some date-palms, called Baal's dates because they have not been planted by man, are a feature in parts of Arabia and apparently near Mesopotamia, while it has also been suggested with less probability that dates near Fezzan or dates in the Canary Islands may be the originals from which the great food-tree sprang. However this may be, it is the most characteristic of all plants of the desert belt from the Western Sahara to India, and especially is it characteristic of the oases.

Buckle long ago went so far as to say that the improvement of the date-palm was the beginning of true civilisation based upon cultivation; this was before much was known about the origin of wheat, and very probably barley, within and especially on the borders of the same zone. But there is no doubt that it has played its part as an important food supplement from early times among the ancient riverine civilisations, and it has been carried and sown by representatives of those civilisations. On the hot, dry coasts between the Persian Gulf and India fish and dates are staple foods, and the date has been a valuable help to a population which made possible ancient intercourse between Mesopotamia and India. Now that we know, from Sir John Marshall's researches, of ancient cities, such as Harappa and Mohenjo Daro, in North-West India and of their relations with the Sumerian civilisation of Mesopotamia, already in the third millennium B.C., these facts concerning life on the intervening coastlands assume special importance, though we are still at too early a stage of the interpretation of these researches to be definite about the routes between the two. It is, at any rate, quite possible that the date on these coastlands was an important factor of the rise of that "pre-Vedic" or pre-Brahmin-Kshatriya" civilisation of India which is now thought to have such large bearings on the development of life in India. The fact that its fruit can be packed and carried for a considerable time is important.

It is equally important to realise that the planting of dates made possible the development of life on many an oasis. There, not only do they supply welcome food, but they also give shade, under which moisture evaporates a little less quickly and plants of other kinds may grow. The development of oases has facilitated desert intercourse and trade, and has, on many occasions, provided opportunity for religious organisation and expression by refugee groups. The date's relation, therefore, to religious evolution in the Saharan-Arabian desert belt is of some importance. · It would be interesting, were there space here, to collect and comment upon the references to the date in the Old Testament, its significance to Israel as a memento of life on the desert border, and the value of the old date groves of Jericho long surviving in a region where the date could not fruit elsewhere save at a few spots near the Dead Sea.

We thus have beech, olive, and date as highly characteristic plants of three belts of civilised life, and through all three the cereals originally characteristic of the date belt or its northern margin have managed to spread, linking themselves in each of the three with a characteristically different kind of agriculture.

By way of contrast we may consider some distributions in Africa south of the Sahara and of Abyssinia. Here, save at a few border spots, barley, wheat, and dates did not penetrate until Europeans brought the former two to South Africa. There was almost no indigenous plant of great food value, and the food plants are such as have been introduced either through Egypt and Abyssinia or by Arab traders and raiders or by Europeans within the last few centuries. Millet from Egypt, maize and manioc from America, and so on, are the characteristic food plants.

Similarly, neither camels nor horses penetrate far into inter-tropical Africa, and the cattle, goats, and sheep do not there lend themselves to transport work or field labour. Transport, and with it the organisation of human society, is thus severely limited, wheeled vehicles cannot be used to any extent, and the region is one of human porterage, while the plough occurred in it prior to European interference only in the north, near the Niger. This absence of animal helpers in part because of insect pests is one of the factors of the widespread and old-established occurrence of slavery in Africa, and it is a commonplace to add that the lowly state of civilisation has made its members only too often the victims of exploitation by other peoples, notably by people of Arab and European cultures, resulting in slavery and various other forms of forced labour and attendant efforts to say to the black man: "Thus far," in civilisation, "but no farther."

In the region under consideration it does not seem that men had a phase of civilisation depending on bronze; organisation had to reach a high level to get supplies of tin and copper, often from different places, and to blend them in proper proportions. If iron is more difficult to work it needs less organisation to get it, and in inter-tropical Africa the smiths are often wanderers not yet incorporated into society. In this region also there are very few places dating back beyond European influences that can be called cities or even towns; indeed, in many areas villages alone are found, and they are moved every few years, and stone building is almost absent in consequence. This is the region also where men associate spiritual powers with specific objects, and have at most a very feeble development of the idea of God save in so far as it has been brought to them by Islam or Christianity; it is a region of scanty clothing in pre-modern times and of the practice of making cicatrices or other decoration schemes on the surface of the body. It is a region that lacks a priesthood with a tradition of learning, and it is almost without writing.

One might add detail after detail here, all showing that south of the Sahara and its Sudanese fringe, of Abyssinia and, one might add, of a line from South Abyssinia south-eastwards to the region of Mombasa, the equipment, food, and customs of man are very different from those to the north. More than that, however, should be said. As one passes that line one comes to populations which typically have broad, flat noses, often everted lips, skins in many cases very obviously adapted, as are nose and lips, to disperse as much heat as possible. We are considering a region in which the heat manufactured by the body through digestion and muscular effort is not easily disposed of, in which, therefore, long spells of continuous hard work are a great strain and mental effort often a much greater one. It is a region that is difficult for mankind, a region into which men have contrived to spread in all probability thanks to the development of special devices for getting rid of heat, devices that, whatever their success, limit effort. It may be remarked in passing that it is useful to look upon the indigenous inhabitant of inter-tropical Africa as a man making at *least something of an environment of great difficulty*, in which we Europeans appear unable to do our own work and so can occupy territory only with the help of schemes, so risky for ourselves, of getting the work done for us.

We may take another example of distributional study by supposing that we have mapped the area of wheat production in Canada for various years from about 1830 onwards. Such maps would show a spread of wheat cultivation westwards from Winnipeg and also northwards from the southerly zone first occupied. The story becomes interesting to the point of romance when it is interwoven with the story of the breeds of wheat. In 1811, Lord Selkirk planted Scottish crofters on the Red, Assiniboine, and Souris Rivers, and, in spite of troubles with the North-West Company, a few remained and began to face the problems of the prairie lands. The bitter exposure in winter, prairie fires, the lack of trees for home building and mending, the problems of water supply, the difficulty of communications over a surface that moisture made sticky, were a few of the problems that might daunt the boldest. The rich, black earth that had once been the bottom of Lake Agassiz, of which several Manitoban lakes are remnants, was the attraction. The early harvests were precarious, the seed wheat apparently poorly adapted to Canadian conditions. In 1842, David Fife got some seed that had come, ultimately, from Danzig. Apparently only one grain from this really ripened, but it resisted rust and other dangers, and its progeny was treasured and multiplied until "Red Fife" became the first standard grain of the prairies of Canada. With its help people moved west, especially after 1869, when the Hudson Bay Company yielded its sovereignty rights to the Dominion; the Canadian Pacific Railway, from the eighties onwards, made this extension faster and more profitable, leading to a growth of farming for large-scale production and marketing by people out to make money, people who would take a holding for a few years and then move on to another. The westward progress had to slacken as the wide rain-shadow of the Rockies was approached, for until recently it has been difficult to produce wheat with less than fifteen inches of precipitation. Northward progress was difficult, because Red Fife needed 120 to 135 days of warmth for ripening. Then came agricultural science with its cross-breeding of Red Fife and Hard Red Calcutta grain, an Indian variety with a short period of growth. The result of this cross has been the famous Marquis wheat, which can do with about 20 days less of warmth for ripening, and wheats with a ripening period as low as 85 days have now been evolved, so the wheat area has spread northward to the North Saskatchewan River and even beyond it. Another wheat, a hard variety called Kubanka, with a long ripening period, has spread in the dry south. Irrigation in Alberta is increasing and is giving opportunity for more wheat, especially near the South Saskatchewan and its feeders, while there is also much irrigable land near the North Saskatchewan in Alberta Province.

It seems possible that a tendency may arise to produce other crops in place of wheat on irrigated lands. Needless to say, another aspect of the story has been the development of railways to carry off the produce, first the Canadian Pacific, and then the Canadian National and Grand Trunk Pacific system farther north. This short statement, it is hoped, will suggest how much there may be that is of vast social and even political importance in the deeper study of what is at first sight such a straightforward question as that of the distribution of wheat production in Canada.

The study of the extension of cotton cultivation in recent years, and of the varying fibres produced in different environments, is another problem that becomes intricate, but illuminating, when pursued on the lines suggested above for the study of wheat. Production has gone some way towards overtaking demand, which is temporarily lower than it should be if real needs were met; if demand increases again, it may be possible to develop further sources of supply, some of which may even now be hardly suspected.

In the case of the beech, we were studying a distribution probably little extended by man's deliberate action; the olive, the date, wheat, and cotton all illustrate man's influence over distribution of plants, his spread of useful plants over whole climatic regions. It may not be amiss to make brief reference to his destructive or restrictive influence on distribution, and to take for this purpose the example of the intertropical forests of Africa. These once had an extension far beyond their present limits; in fact, it has been thought that, within human times, they were almost continuous from the Liberian coast eastwards, and then south-eastwards to the neighbourhood of Zanzibar and farther south across from the Congo Basin to Nyasaland. Probably there were a few breaks in the region of the rifts in East Central Africa. Climate, warming as the Pleistocene Ice Age passed away, has probably made some regions too dry for forest, but a great deal of destruction is due to man, and, when the forest is destroyed and the land left to itself, the growth which appears is very inferior to the original forest. Perrier de la Bathie, in an important study of

Madagascar, has shown that by repeated firings bush may disappear, leaving the land under tough grass with underground storage organs little affected by fire above. Where this appears it tempts further firings, that may even leave the surface exposed to the sun to such an extent that water is drawn up and evaporates, leaving iron hydroxide on the surface to form ultimately a patch of what may be called armour-plated desert.

Destruction of forests in India and China to meet increase of population has altered in several districts the older balance of forest, pasture, and cultivation, with results that have impoverished social life. In the Mediterranean region, on the steep slopes, forests once acted as a sponge to hold moisture and soil in places whence it has been washed down since men (and their goats) destroyed the trees. Moisture now runs off quickly and floods the lowlands, and this has had not a little influence in spreading opportunities for the malaria mosquito. Careful maintenance or redevelopment of forest, on the other hand, as in parts of Austria, Germany, Switzerland, and France, has not only helped to maintain rural craftsmanship, but has limited flood dangers in the lowlands and increased cultivable lands. It may even be that the maintenance of fine rural craftsmanship in wood has had something to do with the remarkable skill that the South German people have shown in fine metal work. At all events, there can be little doubt that care of forest has limited rural depopulation and promoted rural well-being.

CHAPTER V

THE STUDY OF REGIONS

MODERN geographical study is going through a phase of rapid growth and is developing in several directions in various centres. Sometimes it is looked upon as a study in which geomorphology, climatology, plant and animal distributions, and human, racial, social, and economic facts are knit together; and the subject of geography in some university schemes of study is built on these lines, in the hope that with each in charge of a specialist the scheme may work out satisfactorily. In other cases, it is looked upon as a study of the world and its regions, and a teacher who knows a region is specially sought, it being hoped that he will have as competent a knowledge as possible of some, at least, of the technical lines of approach to the survey of his special region. A perfect department of geographical study would provide a specialist on each continent and a specialist in each of the main technical lines of approach, but we are as yet far from that stage of development.

In whichever of the above main directions our ideals lie all geographers are concerned with the gathering together of data concerning regions, and most will defend the importance of at least two kinds of regional study. There is the study of a large and important region in which, while we may try to get first-hand observation here and there, we must be largely dependent on atlases and books and the statements of others. There is also the study of a small region, in the main by direct observation, though it will always be necessary to supplement observation by reference to books, records, and maps. For the latter type of study the name of " regional survey " has come into use, and has been made current especially by Patrick Geddes, whose influence is traceable in many valuable applications of regional surveys, such as those undertaken by the groups replanning industrial regions like the Manchester district, or old centres like Dublin and its neighbourhood, or making plans to limit, or even prevent, the devastation of new industrial regions, such as East Kent. Surveys for afforestation, for hydroelectric power, for land reclamation, and other purposes have been multiplied, and the Colonial Office in recent years has approached the idea of geographical survey as a prelude to administrative action in its schemes of visits followed by reports on East Africa, West Africa, etc.

REGIONAL SURVEY AS LOCAL STUDY

If we cannot all help to explore the high desert of Tibet or the heart of Abyssinia we can at least examine the region round about us with profit to our minds in learning to think objectively of the familiar, and in enriching our associations of memory and the basis of our local citizenship; and surveys of what lies round about us have not seldom led to practical as well as scientific advances. The surveys of Young and of Marshall in the eighteenth century were of great importance to agriculture—the surveys of William Smith brought forth almost the whole of modern geology, while the social importance of surveys made by Charles Booth, William Booth, and many others is most impressive.

There are, indeed, several reasons that make it important to study every region, and to do so at not too infrequent intervals. The county families of a century and more ago performed a valuable service in encouraging the publication of books like Nash's *Worcestershire,* Dugdale's *Warwickshire,* and many another of the kind. These books preserve a record of phases of life that might otherwise have slipped into oblivion, and that would have left a gap no future student of evolutionary sequences could fill. Leland, Camden, and Defoe are names that every student of any locality in England gratefully respects. Survey in this sense is a very old study, and it needs to be prosecuted afresh at intervals in each area that the course of local evolution may be recorded.

The Ordnance Survey in Britain is adding to and modifying its fundamental topographical maps, so that it is becoming increasingly possible to extract from the map details which, when set out separately, will give a picture of the life of the district at some prehistoric period, just as it has long been possible to extract from the map details that permit comparison of the road and railway networks of the twentieth century. To extract analogous details from older editions of the maps and to study them comparatively is one of the best ways of realising the influence of the motor on the road system, while to go still farther back, by selection of the old roads alone, is to demonstrate the increasing sensitiveness to gradient that new means of road-traction have brought about. Local maps of themselves can lead to elucidation and interpretation of many features; they are palimpsests written over with the works of successive generations, and it is a welcome sign of the progress of evolutionary study of human geography that the British Ordnance Survey is providing supplementary maps of relations at various periods in the past. To do this for each locality is a worthy aim for a local student, or a historical and geographical group working in co-operation. But this is only one aspect of regional survey, or local study. However obvious the main relations of the hills, valleys, heaths, and marshes to the geological groundwork of the area may seem to be, there is always the need for demonstration of these relations in the schools and to the general public, and the demonstration in detail rarely fails to lead on to some point that needs scientific investigation. The purely educational value of this work in schools is immense, for it is one of the few departments of school study in which things and men, and not books, are of prime consequence.

There may be changes in the character of one and the same rock-layer that need following and that reveal data helping to reconstitute conditions of a past time, such as, perhaps, that during which the coal measures were laid down. How valuable such reconstitutions have sometimes been to the industrialist it would not be difficult to show. There may be river or coastal terraces that tell of changes of relative levels as between land and sea, and it may well be by comparison of such local observations all along the European coasts that the story of land and sea movements and the interpretation of the phases of the Ice Age may be reached. Local observation is the prime material for scientific architecture in natural history, including therein geology and also geography.

It has been a special service of Patrick Geddes and his followers, the town and regional planners, that they have so abundantly demonstrated the importance of surveys, not only for appreciation of the evolution of the present from the past, but also for preparation for the future. Difficulties may have been inevitable, but surveys might perhaps have lessened the troubles that are now so obvious from the crowding of large populations into the deep narrow valleys of the South Wales coalfield, where opportunities of varied activities and contrasts are limited, and a high degree of specialisation affects a whole community and has led so many to suffer from what might be called psychological isolation. A survey long ago, aiming at protection of open playgrounds and gardens, establishment of quick transit to centres where a more varied social life could have grown, and where directors and managers could have lived near their workpeople, might well have limited, if not altogether prevented, our present troubles. It is, therefore, of the utmost value that guidance is being furnished to those who are developing the East Kent coalfield by regional planners under the leadership of Patrick Abercrombie. The choice of sites for new towns, the planning of new roads and railways that will serve the collieries without scarring the countryside, the preservation of historic and scenic beauty are all parts of the scheme, and, though the planners may not anticipate the future as completely as our grandchildren may wish they had, yet they are giving a new industrial area a start under conditions that should help to spare it from the devastation that has overwhelmed so many of the old ones, and that has told upon the health and general quality of their populations by confining their horizons and encouraging them to forget the valuable motto, *In utrumque paratus*.

There is no area that does not need a survey of its amenities, an effort to maintain its local traditions in building, its open spaces and its open roads, always in danger of undisciplined spreads of ribbons of houses along them, with consequent degradation of open spaces between the ribbons. The Council for the Preservation of Rural England needs to have its good work backed by regional surveys in every part of the land.

It may be asked whether such surveys can ever hope for publication and so for utilisation by a wide public. There are serious difficulties in the way, and not all the work that is done can see the light in this way. It may be hoped that public libraries and museums, and even schools and village institutes, may become depositories for maps and reports of local surveys, and that they may experiment in varying exhibitions of regional survey work from time to time, exhibitions which could do a great deal to raise the level of local citizenship and thus make local government better instructed and more far-sighted.

Surveys of small districts are valuable not only as guides to the preservation of the local evidences of cultural evolution and to the planning of the future in continuity with the best in the past; their value is increasingly recognised in connection with health problems. Here, of course, even the elementary survey of density of population, housing, open spaces, etc., may be of value. But the social and environmental factors in health and disease are increasingly felt to be more subtle and complex than argument from simple demography would lead one to expect. It is for these reasons that some surveys, which study in much detail both the people and the environment of a small region, seem likely to be of value for medical science and practice. It is even suggested that, as is likely *a priori,* the physical types in a population differ in constitutional reactions and in expressive responses within one and the same social *milieu,* and that, for example, phthisis is specially likely to attack those physical types which in particular regions are hard put to it to attain full expression of their powers. Thus, in some moorland areas the acquiescent, dark, long-headed type of man, which is such a characteristic element of the British population, accepts a poor diet and risks of infection and suffers severely from young adult phthisis, while the same type in crowded industrial areas puts up a considerable resistance to the disease, thanks to the ease with which, it seems, he there obtains certain kinds of food. The tall, fair type, on the other hand, with apparently some special sensitiveness to catarrhal infections, suffers severely in a crowded town, but, in the country, he often shows enterprise and is interested in hunting and trapping.

The cure of disease is but a first stage of medical effort; it is everywhere becoming supplemented by effort for the development of health, for the removal of difficulties that have limited growth in past generations, and, in Britain, Scotland has illustrated in a special way the value of regional survey in this connection. Sir Leslie Mackenzie and his colleagues, in a study of the condition of mothers and children in Scotland, have made extensive use of the idea of monographing a small community, and their work is valuable, not only to the health specialist, but also to the student of regional survey, whatever may be his special bent.

THE LARGE REGION

The picturing of the relations between men and their environments is widely held to be one of the chief tasks—perhaps the central task—of the geographer, however much besides geography he may need to know for the purpose of making that picture for any particular region. Travel and languages are among the many important general accessories of geographical study. The treatment of a region will naturally vary both with the region and with the interests of the geographer who is describing it; but, in any case, there is a marked trend away from old methods of treatment in which a statement, often an enumeration, of physical features was followed by a statement concerning productions and trade. The trend, one notes, may be towards a study which proceeds systematically by discussing geology and structure, with special reference to the influence of the facts noted upon the surface features, then climate, flora, and fauna, then inhabitants and their settlements and economic life, and, sometimes, their characteristic modes of artistic expression. On the other hand, there is a trend towards an attempt to unify, by intermingling, these various aspects of a description, and work on these lines may achieve considerable success if the writer's interests are sufficiently varied and if he has the artistic touch that is necessary for the making of a picture. Perhaps Professor Philippson's *Das Mittelmeergebiet* may be taken as a well-known instance of the first method, and Sir Halford Mackinder's *Britain and the British Seas* and Professor Vidal de la Blache's *Tableau de la géographie de la France* as illustrations of the second. Sir George Adam Smith, in *The Historical Geography of the Holy Land*, blended these two treatments in valuable fashion. At the same time, it is to be remembered that books on quite other lines often achieve a considerable scientific success; thus, Doughty's *Arabia Deserta*, describing personal experiences, stands out among studies of regions, a vital picture achieved through a chronological narrative of wanderings.

For many practical, everyday purposes we need information about a particular state or political unit; and many political units represent natural groups in naturally delimited areas, though the exact boundaries are likely to result from historical incidents or accidents that may have led to the inclusion of members of adjacent groups within the frontier or to the exclusion of members of the group located beyond the frontier. There is thus often a claim to treat a continent as a collection of political units to be discussed separately.

On the other hand, the student of land forms, climate, fauna, and flora, races and origins of settlements, and especially the ecologist who seeks to link these, is inclined to treat a continent in natural regions—that is, regions with a high grade of ecological unity. Such a writer may relegate political units to a very subordinate place.

The *via media* is here the wise one, but it is very difficult to find in many cases.

If a State be of old standing, and its main portions have formed part of it for centuries, with frontier adjustments tending, on the whole, towards expansion rather than contraction, as is the case with France, there is considerable reason for taking the political unit as the basis of descriptive and interpretative study, but the natural components of France must be appreciated as contributors to its distinctive personality. There are the three great lowlands—the Paris Basin, with the rivers Somme, Seine, and Loire; the Garonne-Dordogne Basin of the south-west; and the Rhône-Saône Basin of the east and south-east—and in the centre, around which these three are gathered, stands the Central Massif, the highland plateau of ancient rocks broken and diversified by volcanic outbursts of prehuman times. This central mass does separate the three great basins, yet not so completely as to hinder ready intercourse between them. This intercourse, without reducing these regions to uniformity, has led them to a very vivid consciousness of their mutual associations. The strongly felt need for defence has added a further contribution to unity, which has developed very remarkably and has led to a supremacy of the central government over local affairs such as England and Germany have not dreamt of The Albigensian Crusade and the Camisard troubles present instances of local diversities of tradition between Paris and the south, but these differences have long been very minor matters as compared with those between the Po Basin and the south of the Italian peninsula, or between Prussia and Bavaria, or between England and Welsh Wales.

In addition to the main regions just noted, France has an interestingly diversified fringe, with Provençal speech in the south-east, the Basque language in the south-west, Breton in the west, Flemish in the north, and, now, German in the north-east. In the old days of aristocratic rule it mattered little what the dialect of the people might be, but with the rise of democracy has arisen the problem of linguistic minorities. To give up one's cradle language and to learn that which is identified with a higher social stratum is too much to ask of an egalitarian spirit, and devotion to mother tongue is thus often a source of trouble. France has been comparatively happy in the lightness of her linguistic minority problems, for most of the fringing groups speak languages that have not kept up with the modern expansion of vocabularies; they are homely modes of speech that cannot compete with French. It is otherwise, however, with the German speech of Alsace; this has powerful affiliations outside France, and its use, added to the experience of a measure of local government under Germany between 1871 and 1918, makes a difficulty for the Alsatians, who have just become members of the French system once more and find themselves face to face with a more intense nationalism than that from which they were severed in 1871. The gains of 1918 have thus brought to France serious problems not to be resolved by any easy formula.

Beyond her fringing regions France has open intercourse that has contributed to her personality in the most striking way. She is, practically, the western end of zones of intercommunication along the North European Plain, which narrows down to the vicinity of Ypres as it abuts on the Paris Basin, and she is also the most effective western end of Mediterranean routes, with the Rhône and Seine ways continuing those routes to the active Atlantic ports. In a sense, the Paris Basin is also a terminus of the routes from the Danube Basin westwards, though of old some of them joined rather the ways westward along the North European Plain, as the spread of prehistoric Danubian civilisations suggests. The Continental routes converging westwards on the Paris Basin have made its life an interesting blend of northern and southern features, and have, therefore, greatly enriched its individuality, and helped it to spread the influence of that individuality once it had grown.

It will be of value to look into the matter of the natural regions within France in more detail. The southern regions of France were all considerably Romanised under the Empire, the south-eastern Provincia, that became Provence, naturally most of all. The Roman influences in the life of these regions, carried on by Visigoths and others, maintained a considerable measure of continuity throughout subsequent centuries, so that, on the regrowth of some elements of order after the worst of the Dark Ages, the south was ready to "receive" Roman Law, and, as its Romance dialects took shape, they retained more memories of Latin than those farther north and are classed under the group name of Langue d'oc. But the South of France is a series of dissimilar and disconnected subregions with very different opportunities in the past and interests in the present; even the railway era of communications has diversified rather than unified the south. Provence itself divides very sharply into the Riviera, with its tourist luxury and its new Alpine railway to Coni; the Rhône, with its high-grade cultivation and its transhumant pastoralism (of the Crau and Camargue), but also its great port of Marseilles, now linked by a canal tunnel to a future great harbour and industrial centre around the Étang de Berre, and thence to the Rhône; and the back country grading into Alpine poverty. Languedoc is less sharply divided within itself, but stands out over against Provence by having its wide plain and its background of little coalfields in the Huguenot centres among the valleys of the Cevennes. Roussillon, to the south, is a warm little corner more than half Catalan. The other parts of the south farther west differ from Provence, Languedoc, and Roussillon in not having the olive—they are less Mediterranean. There the Garonne Basin acquired wealth centuries ago by sending wine to England, and the coming of maize later on modified its agriculture. Between its lowlands and either the Pyrenean slopes where, on the west, the Basque language lingers, or the Central Massif with its narrow valleys and rugged heights, the contrast is a sharp one. The southward projection of the Central Massif may be said to be the greatest obstacle of all to any unity of the south.

Contrast with the south the great basin of the Loire and Seine, usually called the Paris Basin, farther north. Its rivers form a focussing system of themselves, its geological formations, more or less in concentric rings, give varied soils with, on the whole, a good balance of woodland, grassland, and cultivation; and its reasonably assured summer encourages wheat growing as the central activity in a scheme of mixed farming. Roman power made itself felt in this basin, but mostly at centres which in due course became bishops' towns in most instances, and, largely owing to this, survived the period of decay and poverty which came after the rise of conflict between Christianity and Islam had cut off the trade which had brought prosperity under the Roman Empire. The Paris Basin lacks the olive entirely, but is able in selected spots to grow the vine for several choice wines (Champagne, Saumer, Chablis); this contrasts with the widespread production of inferior wine that goes on side by side with the careful maintenance of choice vintages in the south. Wheat, vineyards, or apple orchards, stone-fruits, cattle, market gardening, and industrial cultivation make up a diversified agriculture carried on by a population that is fundamentally a land-loving peasantry, using the towns as market centres which have become modes of an interesting economic life largely self-contained within each region, but having fairs and other devices to bring in an element of more or less external trade.

The market town of the Paris Basin has its cathedral often dominant, its streets devoted of old, and sometimes still to-day, to particular trades, and its outlying abbey that has typically become a parish church and has developed its former outbuildings into hay and corn stores and inns for carts on market days. The whole has a characteristic type and feeling, and there is a marked resemblance between many of these towns. There may be a castle, but that is a less frequent feature than the church; a town hall and belfry apart from the church is not part of the traditional scheme in the centre of the basin, though it appears towards the borders. Not only is the market town a characteristic feature of the Paris Basin, its church architecture is even more striking as a speciality. This is the first great home of the misnamed Gothic style, born in all probability in or near the Île-de-France and supplanting the older Romanesque in most places. In the south of France, on the other hand, the Romanesque style revived and endured, and only very rarely in that more Roman part of France is a Gothic design pure and successful. There are several conspicuous efforts that are not far from failure—the cathedrals of Montpellier, Narbonne, and Toulouse, the last contrasting, unfortunately, with the fine Romanesque St. Sernin in the same city.

Whereas in Britain with our risks of bad harvests and our coal-industrialism the people have to a large extent lost touch with the land, the French peasant is still the backbone of the country, though in the Paris Basin even he is being drawn away towards the towns. In the south the townward movement has been more marked and the areas of poorer soil are losing their populations at an alarming rate, while Italians, Poles, and others are entering the country, mainly as hands for industrial schemes—ironworks in Lorraine, refineries in Paris, and so on. Still, fixity of the villager makes the employer ready to welcome immigrant labour. The unity and solidity of the peasantry of the Paris Basin and its magnificent focal scheme of river and road communications have given rise to the great capital, and have assured it a unique influence in the country generally; and since the thirteenth century the conflicts of the various regions of north and south have resolved themselves for the most part in favour of Paris. In the seventeenth century Paris developed a centralised government for France, and this has gone on, with some adjustments, ever since. Its maintenance and development have owed a good deal to a fear of Germany, which has become more and more acute in recent generations as the personality of Germany has become more defined and German man-power has multiplied itself so quickly. This has made France, and, most of all, the Paris Basin, peculiarly conscious of itself. It has emphasised the personality of France as a nation of peasants led by a centre of thought and art, a people among whom trade is a subordinate activity and external trade a supplement, a people strongly inclined to be self-contained both in their economic life and in their thought, distrustful of internationalism, which is considered by them as a danger to defence that may be necessary at any moment, worshipping the sacred soil of the Motherland. A little work of this kind has space but for the shortest of outline sketches, and, in drawing one of a region, France has been chosen as an example with the most marked personality developed through long centuries of a continuous peasant and bourgeois tradition, whatever may have been the changes of high politics. The contrast between the continuity underneath and the discontinuity above in France and the discontinuity beneath obscured by the continuity above in England, is a striking feature of Western European life, and creates many a difficulty of mutual understanding between the two peoples. The discontinuity in England has involved a change from the land to external trade as the mainstay of life; the continuity in France has made this change in England seem to not a few minds vulgar and a proof of an aggressive temperament. The development of industry, which has followed the reconstruction of Northern France and the retrocession of Lorraine to France, may well affect this attitude and help a larger number of French citizens to understand more naturally the English attitude.

It is characteristic of France that Paris, Marseilles, and Lyons are the only three cities with more than 300,000 inhabitants; Bordeaux and Lille have between 200,000 and 300,000, and about ten other cities between 100,000 and 200,000. The smaller Great Britain, with, it is true, a seven and a half per cent. larger population, has, apart from London, nine other cities with populations above 300,000, nine more between 200,000 and 300,000, and twenty-six between 100,000 and 200,000. Rural depopulation is occurring in both countries, but it has progressed farther in England, and we are an urbanised nation, a people among whom the standards and feelings of the town spread to many a far corner, so that there is far less difference amongst us between the townsman and the countryman than there is still in France. The Briton of a generation or two ago felt the lure of the empty lands in far continents, and the more adventurous streamed away; the French peasant has from antiquity felt, and still feels, that what is almost a moral stigma is attached to emigration. The exceptions to this feeling are mostly cases in which special reasons have intervened. The study of geographical relations of the peoples of France and England thus brings out point after point of comparison and contrast, shows that diverse social traditions have affected the two countries, and have given diverse tints to the temperaments and personalities that vary from individual to individual in France as they do in England. We may not speak of a typical Frenchman any more than of a typical Englishman; we may try to understand typical English and typical French social traditions.

Having now sketched in brief some features of a region with a most marked personality and a high degree of unity throughout most of its constituent pasts, due allowance being made for the special case of Alsace, we may consider by way of contrast another region in which unity, and what it is permissible to call personality, has been far less able to develop, in spite of rather clearly marked frontiers and certain similarities running through wide areas.

India is a southward projection from the Asiatic land mass into the Ocean. It has thus been, to a certain extent, an ultimate goal for drifts of humanity, especially for early ones who having got to the south end were ill equipped for a long sea voyage. This is a partial truth which requires the supplementary statement that there have long been maritime commercial connections with both east and west from the south of India and especially from the south-west, which has a distinctive population, uses a Malayalam language and turns its attention seawards. Within India itself the primary division of natural regions is that setting Peninsular India in contrast with the Indo-Gangetic lowland and the varied mountain frame, but each of these is composed of several different elements. The peninsula is mainly the great plateau of the Deccan rising northward in the broken highlands that mark off the peninsula from the lowlands to the north; its western edge is also high and sharply cut, and beneath it is the hot, wet west coast. The broken highlands have been a typical impediment to southward penetration in India, though the fact that they are broken implies that there are important ways through. The west coast has a high monsoon rainfall and large rice crops; the Deccan gets less than forty inches of rain and mainly grows millets. The east coast lacks the regular hill-edge of the west as well as the heavy rainfall and rich forests of that side, but the deltas and lower courses of rivers grow large quantities of rice. The Indo-Gangetic lowland is strikingly differentiated by climate. The monsoon rains are heavy and long continued in Assam and Bengal, but diminish farther west in quantity and in duration, clinging most to the Himalayan slopes. The Indus Basin is thus far drier than that of the Ganges; it grows wheat under the influence of winter rains, whereas Bengal depends rather on rice cultivated in connection with the monsoon rainfall. The mountains of the west are mostly dry and bare, the abode of the Pathan; the Himalayan, on the other hand, are richly covered with forests up to great heights and contrast most dramatically with the barrenness of the Tibetan highland beyond the line of the watershed. The subject of the natural regions of India has been discussed in the magazine *Geography* in 1928 and 1929 by Messrs. J. N. L. Baker, L. D. Stamp, and F. J. Richards, and Miss E. Simkins recently published a study of *The Agricultural Geography of the Deccan* (London, G. Philip, 1927). These publications will be found useful for amplifying the short sketch just given.

Drifts of men have probably moved, in the main, southward through India, for it is highly improbable that India was the first home of man. To understand them more fully it would be advisable to argue out a reconstruction of the Indian environment in early prehistoric times, a precarious matter with the data at present available. The early drifts of men, whencesoever they came, may be supposed to have got into the Deccan from Asia farther north or north-west. Later these lowly and early peoples found the forested highlands of Central India, the forested mountains of the south and the heights of Southern and Eastern Assam to be refuges against the onset of conquerors. They are all regions that catch large shares of the great monsoon, and in these forests survive remnants of early peoples with lowly modes of life, so that Baden-Powell could describe groups that made a village in which they lived for a few years before moving on to fresh fields to repeat the process. The shifting village is a feature of lowly forest agriculture in parts of equatorial Africa and Madagascar; the Japanese have found indications of it in Northern Korea (Cho-sen), and Professor Childe has argued for its occurrence in antiquity in Central Europe. It may well be an almost universal accompaniment of early agriculture save where, as near the Nile and Euphrates, floods renew the fertility of the soil year by year.

The forested refuges, with old populations such as the Bhils whom Kipling has pictured in *The Tomb of his Ancestors,* contrast with conditions in Western Europe, where almost equally ancient elements seem to occur, but are to be discriminated from their neighbours only by anthropometrical detail; even if they are found in remote spots, such as the Dordogne and the moorlands of North Portugal and Western Wales, a number have made efforts to come out of their remoteness, and in the effort have produced quite a proportion of supernormal individuals.

The general population of India may be described as a peasantry, and a moderate estimate of the proportion supported by agriculture is seventy-five per cent of the total. Of its origins and lines of drift we know little, even if we surmise that the growth of cities in the north-west in the third millennium B.C. had a good deal to do with the spread, or, at any rate, the increase, of agriculture in India. The languages usually held to be associated with the general population are those of the Dravidian family, and the name Dravidian has been used for the peoples and even for their race type. One could hardly venture to say whether or no these languages were imposed on the people by conquerors, or were evolved amongst them, so there are risks in using a language name for a race group. Pressure of subsequent drifts from the north-west seems to have restricted the Dravidian languages for the most part to the Deccan, where one or other of them is in use in most parts, though the influence of languages of conquerors from the north has made itself felt. The presence side by side of aboriginal jungle peoples, a general peasant population with its aristocracy and its craftsmen, its townsfolk and merchants, and military rulers of alien stock is generally held to be one of the factors of the rise of caste. To this factor must be added others of myriad kinds—occupational groups, ritual groups, *parvenu* groups, and many others, discussed by Risley in his book on the people of India. The caste system is apparently extraordinarily complex in parts of South India. Contrasts of race and tradition, the presence of the untamed forest, the hatred of digging among military conquerors arriving from cooler regions, have all conspired to hinder unification of the people in any real sense, especially as the level of information concerning anything outside the village remained and remains low. In the absence of either regional unification or the establishment of any considerable measure of a common mind which would have steadied social organisation, the system of caste, though always changing, has, nevertheless, provided a certain stability.

The Indo-Gangetic trough was invaded probably in the second millennium B.C. by the Indo-Aryans, as they are often called, a military aristocracy with horses and swords; it is they who have also sent aristocratic groups into the Deccan. They appear to have found a good deal of the Indus basin open country, but, as they penetrated down the Ganges Basin, forests became more dominant in correlation with heaviness of monsoon rains, and the type of the invader, with extremely narrow long head and narrow nose and high stature, becomes rarer; the forests acted as fractionisers, and the conquering elements became a smaller, the general or basic population a larger, element. It seems natural that in what are now the United Provinces where this process of fractionising seems to have begun, at least in any serious degree, caste is specially complex and intricate, ancient royal cities abound, and early history gives names of ancient kingdoms of special interest. Hinduism, an amalgam of the religious traditions of the military conquerors with many an older and more indigenous element of culture, dominates the region save in certain parts, as will be mentioned hereafter. Religion expresses itself most of all at one of the great foci, the holy city of Benares, far down the Ganges Basin. The peasant village of cultivators is very often in the hands of a lord, or zamindar, who belongs rather to the conquerors than to the villagers themselves. In the Deccan, on the other hand, the village headman is often related rather to the villagers, but such statements are necessarily subject to many modifications. While the village of the upper Ganges Basin may depend mainly on grain of various kinds (wheat, millets, etc.), the village of the lower Ganges often lives on rice almost exclusively, and the monsoonal floods followed by a fine season are a factor of this type of agriculture, which in its turn is a factor of a dense population apt to live very near the limit of subsistence.

Without attempting to follow the so-called Indo-Aryan conquerors and their influence further, we may note in passing that, though later military groups, such as those led by Mahmud of Ghazni in the eleventh century A.D., and that to which the Mogul Emperors belonged, have won power over the north-west, some of the Indo-Aryan groups maintain the Rajput sovereignties characteristically organised on various patches of good soil in and near the desert of Thar. Such territories inspire tenacity of defence in and on the brinks of the deserts across or around which intercourse is maintained. Among subsequent conquerors of the north-west, Islam has been a great force, coming into India fully fledged to encounter a long-matured Hindu tradition, and the two have confronted one another in as determined a fashion as Christianity and Islam confronted one another in Spain. But in this case Islam had contact with its other provinces across the border, while Hinduism lacked the aggressive strength of Christianity, and the result has been that in the north-west the two remain in steady opposition to one another; the conflict has not resolved itself as it did in the case of Spain. Only in the Punjab is Islam in a large majority; elsewhere Hinduism is usually dominant, but in Bengal Islam has made great advance, gaining, it is said, many converts escaping from the caste system into the relative social freedom of Islam; and in Bengal Hinduism counts only some eighty per cent. of the number of adherents of its rival.

Delhi, at the western entry into the Ganges Basin, may be thought of as the forwardly placed capital of Islamic rulers, facing towards the ancient stronghold of Hindu tradition in the United Provinces. It is at the south-eastern end of a relatively narrow belt of fertile plain between the Indian desert on the south-west and the foothills of the Himalaya on the north-east. The desert to the south-west, as it were, negatively determines lines of south-westward communication—that is, it pushes them eastward beyond its limits so that they are related to the Aravalli Hills and reach the Ganges Basin near Delhi; their other ends are round the Gulf of Cambay.

Without any attempt at completeness, the foregoing sketch has tried to bring out that the Deccan, the forested heights of Central India, the north-west, the Gangetic trough, and the north-east all have their marked individualities; each is unassimilable by the others so far as can be seen at present. In mere size, India is roughly of the magnitude of Europe west of pre-war Russia, and, though it is rather more compact than Europe, its surface and conditions of life are much more highly diversified. Moreover, it is a region in which there is not, at any rate as yet, that surplus energy which inspires the restlessness that makes for a rise of the economic level. The Indian peasant, near the limit of subsistence, seeks little beyond the bare necessities; he is acquiescent in material matters, however moved by spiritual considerations which engage his interest. There is thus little stimulus towards large scale unification of organisation save in so far as it is contributed by Europeans or by Indians who have made contacts with Europe. Left to itself, Indian social life is mainly static. India is committed to multiple personality for a long time to come. Moreover, the population is so largely rural that the influence of focal cities on social organisation and control is not very great, however powerfully the ritual of Benares may draw people to the sacred river. In not a few of the major regions of India there is no city that is really an effective control-centre for its region, much less is there any one such city for India as a whole. The contrast with France is dramatic. Paris has been *la ville lumière* to France, or, at least, has thought of herself in those terms; her influence has come to dominate the whole country, has focused the expression of the people in art and thought and politics, and has given rise to a centralised scheme of government. None of these features has developed in India, and even far-reaching British interference is not able to impart or counterstimulate unity.

Prior to the coming of Europeans by sea, maritime influences, save those working coastwise in ancient times from the Persian Gulf, seem to have been subordinate in India. The Malayalam language has been mentioned, and one might also mention the small but powerful group of Parsis in Bombay. The trading forts of European navigators around the coasts of India mark a new type of contact and penetration, and the domination of Britain exercised through Madras, Calcutta, and Bombay is a power acting in directions contrary to the historic ones, as well as working by methods very different from those of earlier conquerors. The penetration of Britain from Calcutta has been towards the north-west, and if, of late, Delhi has been made, by a conscious effort, the centre of British rule in the political sense, commercial life still centres upon the great ports. Reflection on this will show how alien the British scheme is to Indian tradition and how much has to be done by education on lines related to both Indian and British culture if any large measure of real assimilation is to take place. The new commercial life has developed the idea of large scale production for export, an idea foreign to older Indian thought, and has followed this up by establishing factory industry, thus effecting another revolution. Its agents selling western manufactured products have apparently weakened Indian craftsmanship, which it is thought by many was already waning when British commerce entered the country. India, as a whole, is clearly working through an unexampled crisis in her historic life, but neither the spread of British ideas nor the opposition to that spread as yet gives any prospect of a growth of effective unity among its varied peoples. They live in a great country, the bounds of which are fixed as sharply as those of any kind of region on earth except an island. It is specially incumbent on British citizens to study India and to try to look at its social systems and economic life with real objectivity. The foregoing few remarks, to which many qualifications should have been added, will, it is hoped, be stimulating for purposes of such study of one of the great regions of the world, a region teeming with men for whose welfare Britain has accepted a heavy responsibility.

It is impossible within our narrow limits to develop the whole argument of the study of a region, to balance up different methods, or to give a worked-out example, or even a table of contents. It has been thought that it would be more appropriate to mention some important problems with which study of a region confronts us, and thus to help to show that geography is not a subject in a water-tight jacket of technicalities, but rather one which brings out vividly points of many kinds connected with practical life. The two cases chosen are strongly contrasted, and in both the attempt has been made to look at the whole.

CHAPTER VI

INTERRELATIONS OF REGIONS

One of the pitfalls in the path of a geographical thinker is that of giving attention to nothing but the region under immediate consideration, of arguing forwards and backwards between the features of the region and the activities, organisation, and modes of expression of its people—that is, of interpreting the characteristics of the people's life and work in terms of the features of the country in which they now live. Such concentration is apt to blind the student to the play of factors from outside; the people may have brought with them many activities long practised elsewhere, or they may have had habits imparted to them by conquerors from abroad, as was notably the case in England after the Norman Conquest, and still more in France after the Roman Conquest. An account of British lead mining worked out some time ago gave careful attention to fluctuation of production, but missed many opportunities through omitting entirely a consideration of the entry into this country of supplies from new sources cheapening the price of the metal at various dates, and so making the receipts of lead mines fall below their working costs. In particular, the quantities per British mine were often small in comparison with those available from some foreign sources, and so transport difficulties and costs were an added handicap. Nothing can be isolated and treated *in vacuo.* Imported elements of culture, external relations, or distant supplies may profoundly affect a region's life and work, and it may be of use to refer here to a few examples.

The first, though far back in the past, is really one of the most dramatic in the life of the world; it concerns the advent of civilisation in Europe. Civilisation in a broad sense may be taken to imply a social life with deliberate food production—that is, with an organisation, a continuity of tradition, and a sequence of activities more regularly devised than those found among peoples living by hunting and collecting. Cultivation and the keeping of domestic animals are the fundamental modes of food production, and the art of cultivation, by linking men increasingly to the soil of their homeland, has played a specially important part in the development of civilisation because it has made accumulation easier and has thus allowed credits from one generation to be carried on to the next to an extent previously impossible. Hunting and collecting peoples lack effective writing, a learned priesthood, cities and temples, and many other features that are widespread among cultivators, though not universal, as has already been mentioned in the discussion of distribution when dealing with Africa.

European civilisation is clearly based on cultivation, and barley and wheat are the foundation of our cultivator's art. But neither of these plants is native to Europe, and until they were introduced North-West Europe was a region of poverty in a far corner of the world where survivors of the Old Stone Age seem to have lingered on, hunters with their life impoverished by the growth of great forests over what had been spreading grasslands in the cold days of the declining Ice Age. The grassland beasts were reduced in numbers; the forests, at first of pine, were unfriendly.

The grains barley and wheat belong to South-West Asia and the former also to North-East Africa, and from some part of the riverine lands of that region the art of cultivating grain advanced towards Europe, penetrating through the centre westwards, apparently in the third millennium B.C.

The centre offered a zone along which people could move and settle, the belts of loess soil. Loess is moderately fine-grained, porous material that seems to have been blown into its present positions by winds blowing out over the edge of the glaciers of long ago. It has sometimes been rearranged to some extent by water, but it still floors a belt across Russia, a zone around the outer side of the Carpathians and the mountains north of Bohemia, and large areas in the Danube basin. Analogous soils occur farther west right into the Somme basin (*limon des plateaux*). The map of these soils, given by Vidal de la Blache in his *Tableau de la Géographie de la France*, is a document that every student of European life should know. About the same time there arose in the Mediterranean Sea the civilisation of the port cities, with olives added to cereals as part of the food and commerce scheme, and before the third millennium ended the fame of Cretan Knossos and of Hissarlik the Second was spread far abroad. There also arose in Central Europe villages with cultures which developed marked individuality early in the succeeding millennium and gave Europe its local cultures of the Bronze Age. The maritime spread along the Mediterranean continued northward along the Atlantic coasts, and there came into relation with the spreads that had followed the loess belts across the centre of the Continent. Thus Europe was wakened in all its parts, and varying expressions of the same fundamental features, coming by different routes, met in the west and fertilised one another. The meeting of transcontinental and maritime culture streams in the Stonehenge-Avebury area is a conspicuous fact of archæology, and the occurrence of an amber bead from the Baltic and a blue bead from the south in one and the same grave in Wiltshire illustrates the point with dramatic clearness.

The rise of Europe to importance, once it had grain and domestic animals, is in part due to these resources, but also is it in part due to the fact that men were now more fully able to enjoy the advantages of a climate that, in Western Europe, permitted the maintenance of activity and even of keenness throughout the cycle of the seasons among people who could now make durable homes and attach themselves to one particular patch of soil. From that time onwards the vigour and initiative of European peoples has been an important, if a disturbing, element of the world's life, though the dominance of Europe that was so marked between 1800 and 1900 developed thanks to utilisation of machinery and of coal and steam.

The development of civilisation based on grain and domestic animals occurred first in South-West Asia or North-East Africa, or both, and was accompanied by the rise of many new arts and crafts which students of prehistoric archæology are able to study by means of finds of pots and implements. The distribution maps that are emerging in the course of such studies will some day help materially in tracing out the spreads of civilisation the world over and the mutual influences of the cultures developing in various regions. Grain came to Europe, and with it spread the idea of the village, developing from a temporary to a permanent one on the European loess areas, and spreading thence little by little in Europe north of the Alps during the last two millennia B.C., with many vicissitudes, including a severe set-back apparently connected with a phase of chilly, damp climate during part of the last millennium B.C. Meanwhile, as already stated, the Mediterranean Basin had become a region in which villages had become cities; the spread of the cultivation of the olive was a great aid here, though not a fundamental factor. It is of the greatest interest that the full idea of the city did not reach Central and Western Europe until the Roman Empire brought it. The contrast between the lands of the Euphrates and Nile on the one hand, and Central and North-West Europe on the other, was apparently too great, and the insecurity of the heavily forested Europe of those days too serious, to permit of the growth and continuance of large settled groups such as are required for the development of cities. The Roman Empire, with its systems of roads and laws, advanced in Western Europe to Britain and the Rhine, and in Central Europe to the Danube and Dacia, and wherever it took firm hold it planted the idea of the city. In its outlying parts, such as Britain and Dacia, the cities that grew up fell again, for the most part, when the imperial system decayed, but the more Romanised lands, notably France, kept the city tradition alive through the period of poverty and disorder when conflict between Christianity and Islam stopped for a while the time-honoured streams of trade of the Mediterranean. It thus happens that the idea of the city was spread over Europe north of the Alps in two main stages, with an intervening lapse into poverty and disorder.

The second stage occurred as Mediterranean and general trade began to re-establish itself after the period of disorder, and a number of Roman cities in the Paris Basin, especially those such as Sens ruled by bishops, grew once more as has been already explained. The Roman cities of the Rhine, as, for example, Cologne, shared in the same growth, and thence the idea of the city spread eastwards with some modifications. Sometimes the Church, so closely associated with the early cities of Gaul and the Rhine, pioneered, and the Church became the civic centre in these cases as it so often is in the Paris Basin, but in the wild lands defence was an outstanding need, and the castle often, therefore, took precedence. The dominance of the castle at Nürnberg and the centrality of the Church and the great position of the bishop's castle at Würzburg tell their tale. Whereas the cathedral seems to have dominated most aspects of the life of the bishop's city of the centre of the Paris Basin, the castle of the German city rarely achieved quite so much, and it is characteristic of many of them that there is a burgher's centre, a town hall or rathaus. This element in their life apparently reached them through the Flemish and Hanseatic trading cities (Lübeck should be studied), which began to acquire widespread importance as the threads of the commerce were woven into a web in the eleventh and twelfth centuries. With the rathaus or town hall in several cases appear guildhalls of the various crafts and branches of commerce, and a town church on the market place may be the religious centre of the burgher's life, distinct from the cathedral under the bishop and the chapter. The broken topography of Germany east of the Rhine contributed to delay, and even to prevent for a very long time, the growth of political unity, and it is characteristic that the infiltration of the Roman idea became, on the whole, less and less complete with increasing distance from the Rhine-Danube frontier of the ancient Empire. Thus, when Roman law was accepted as a way out of local confusion in parts of the fifteenth-century Germany, it was those parts that were nearer the Roman frontier which accepted, while those farther away kept to Germanic custom. And the religious schism between Roman Catholic and Protestant in the sixteenth century illustrates the same principle, with some differences usually connected with the influences of rulers—the principle *cujus regio, ejus religio* having a surprising degree of validity.

It thus appears that in the cities, law and religion of Renaissance Germany, and thus in a measure of modern Germany, we have conspicuous examples of importations of culture and so of cultural interrelations of regions. The importation is not a mere transference, it usually involves an adjustment, and the reactions which it promotes round about are often, as in this case, the source of new features. In social matters actions, direct influences, are often hardly as important as the counter movements they provoke.

It is interesting to trace the city farther east. There, especially among people of Slavonic speech, the civic idea, brought apparently by Romano-Germanic leaders in religion and war, was planted among people of other speech, and Church and nobles gathered together, giving the highly characteristic dual city, one element having the castle and cathedral, the latter inside the ring walls of the former, the other having the burgher element, the craftsmen and labourers. Prag and Cracow are admirable illustrations here. At Prag, the Hradčany stands high on one side of the river, the commercial city with its town church stands lower on the other.

Among many of the cities of Eastern Central Europe there are traces of another modification that the idea of the city has received in its spread. The older established population is essentially rural, and the city may have been founded by swordsmen and churchmen from nearer the Rhine-Danube. The city thus begun afforded an opportunity to people from older cities to come in, and one finds indications of strong German tradition in some cities where the rural population uses Slav languages. Still more does one find the powerful and persistent Jewish tradition in many a city of the region in question, a tradition derived from the West, from Jews often repressed as Germanic organisation grew in their earlier homes near the Rhine. There have thus been towns with German elements especially among the leaders, Jewish elements especially in the humbler streets, but with leaders emerging persistently, and these towns have often been set in Slavonic speaking areas, offering to political organisations the most difficult problems. The German or Jewish elements, or both, long resisted, and not seldom still resist, all attempts to assimilate them to their Slavonic neighbours, who, as their life expands, find its natural expression already provided by people of alien culture and even alien religion. They have had difficulty in making their way into the centre of the commercial life of the country they and their forefathers have peopled, and there have been bitter enmities and political weaknesses as an inevitable consequence.

The student of the Treaty of Versailles and its references to the protection of minorities will often be puzzled to balance the justice of political actions in such a complex situation, and may become aware that in that treaty there was a great effort to carry eastward a further culture, spread from the west—namely, that of organised nationality. It is a large question for practical men whether the national idea is the only one of use in forming governmental areas and organisations, as is often assumed in schemes drawn up by Western Europeans. Indeed, this and other assumptions, often made more than half unconsciously on the part of Europeans, with the result of confusion worse confounded, as in the question of native lands in several parts of Africa, illustrate with dramatic intensity how important it is to develop a scheme of geographical education that shall include and go beyond the study of places and features by enumeration, beyond the discussion of physical features and economic products, deep into the questions of social life and tradition, land tenure and agriculture, and social, artistic, and religious expression of peoples in varying environments under the impact of varying immigrant influences from without. This discipline of study is in the stage of its early growing pains, and offers a field for the progressive thinker.

Returning from this digression and following the city idea still farther east around the Pripet Marshes, one of the greatest separators of mankind for ages, there is seen to be further adjustment. The castle-cathedral element is paralleled by a "Kremlin," a centre with churches and palaces, barracks and chancelleries, surrounded by a wall that dominates a square or parleying ground, beyond which, as in the case of Moscow, lie the radiating tracks of the vast plain with their termini near that city's Kremlin, bordered by booths and huts now crystallised into stone and with churches galore, especially at stations of pilgrimage. How far the Kremlin is an adaptation of the 'castle-and-cathedral-city side by side with the burgher-city' in lands farther west, how far it represents an adaptation of the trading fort scheme, strongly guarded in the midst of a potentially hostile population, and how far it may even have a lingering inheritance from the Greek idea of the Acropolis, it is not necessary to argue out here. For the present purpose it is enough to see that something which is characteristic in a high degree of Russian cities is to be thought of both as in part an assimilation of imported attitudes and as a human reaction to a particular environment.

As another example China may be briefly considered. The name has come to be characteristic of a great area north-east and east of the Central Asiatic mountain chains that make up Tibet. The Yangtze-Kiang, one of the world's most important rivers, divides North and South China from one another physically, but furnishes a means of intercourse for a long distance east and west. The great river of the north is the Hwang Ho, which emerges from mountain corridors into trenches between blocks of old rocks, and after flowing through them pours itself out on an alluvial plain. Nowadays its mouth lies north of a broken and isolated old block of land that forms the outstanding peninsula of Shantung, but it used to reach the sea south of that peninsula. The Wei-ho, one of its most important tributaries, flows between those eastward continuations of the Central Asiatic mountains that are known as the Tsin-ling-shan and one of the old blocks to the north. Near the upper part of the Wei-ho River there are ways towards Western Asia through Kansu, the name of the region just beneath the north-eastern fringe of the great mountains, watered by their streams, and thus saved from the barrenness of the desert plateau of Gobi farther north.

China has long been proverbial for changeless continuity and isolated pride, a self-contained life fixed as if for ever. Special students have drawn a better and fuller picture than this, but the existence of this prejudice makes it useful to take up the case of China as one within which one can see a great deal of the results of inter-regional relations. The Wei-ho Valley is sacred to Chinese early history which gathers so particularly around the city now known as Sian (Hsi-ngan-fu). It is from this valley that the essential civilisation based on agriculture spread eastwards and southwards. That it had spread into the Wei-ho Valley from Kansu is held by many students, and that it owes something to cultures farther west—for example, in Mesopotamia—has been held by some who have seen, in the painted pottery discovered by Andersson and Arne recently, a likeness to the painted pottery that evolved in early Mesopotamia. This question of origins is beside the point here save that it suggests the high probability that the very basis of Chinese civilisation may be imported—the careful irrigated cultivation that is gardening rather than farming. The adaptation of this scheme of life to the massive loess of the Wei-ho Valley, with the leading of the water to the cultivated patches, was followed by its adaptation to the low alluvial plains farther east, where canals are dug to lead the water away and mud is scooped up to be laid on the fields as fertiliser and to keep the drainage scheme open lest floods spoil all.

The penetration of Chinese culture southwards is one of the main features in the story of China. On the alluvial plains north of the Lower Yangtze the problem has been that of making canals, and in a non-mechanised civilisation such as that of China this has led to minute subdivision of land and dependence on hand labour, a scheme of society also encouraged by the rites of ancestral reverence and the thence arising insistence on the maintenance of the family. These facts and the associated gardening and accessory crafts naturally give the large family and the densely settled population, and lead to the destruction of forests. One finds in North China that the process of intensification has gone so far as to reduce to a minimum the numbers of domestic animals. Pack animals remain available on the borders of the Mongolian desert, though human carriers are a feature of Chinese life. Though subdivision of land has been carried very far there is a widespread hesitation to divide a family property, and the complex family has been the typical unit of Chinese life—that is, a family, including married descendants of the original founder and their children, and sometimes other relatives as well. Some writers of a generation ago were inclined to look upon the complex family as a modification of the tribe of the nomads of the desert, and this is possible, but hardly certain; the complex family, in other words, may be fundamentally an importation or may be a result of reactions *in situ* in North China.

Whatever its origins, the family, in an extended sense, has been the typical Chinese social group, providing for its faithful members and demanding their complete loyalty. The family as the centre of social vision has given Chinese life a static quality of stability, and is generally held to be responsible in large measure for the lack of development of a nationalist point of view; some would make it also responsible for the series of foreign dynasties which have found it possible to manage China. A Chinese gentleman, lamenting the disruption of the traditions of his country due to recent contacts with Western Europe, expressed a characteristic point of view by saying that he feared China would have to develop the aggressive vice of patriotism in order to guard the yellow civilisation against the white peril.

It is of considerable interest that the Chinese and their various rulers in North China have in due course created historic cities, usually at transition points: Sian in the Wei-ho Valley; Peking in the north, between the sea and the Mongolian plateau and between Manchuria and China proper; Tsinan at the limits of the Shantung highlands; Nan-king where the Yangtze is becoming maritime; and the great trinity of Han-kow, Wu-chang-fu, and Han-yang-fu centrally placed on the Yangtze, where the plains stretching south from Peking meet the great river and find opposite direct possibilities of communication with the far south. How far these cities, in their fundamental characters, are to be considered as a result of evolution *in situ,* and how far as expressions of imported ideas, might be debated at some length. It would seem that the first-mentioned point of view has much value in relation to them, and, if so, it may well be that parallelisms with cities elsewhere are, in large measure, true parallelisms—that is, practically independent evolutions from separate beginnings, rather than cases of spreads of one idea from one original home. This is, however, a matter of more academic than practical interest, and it will be left here without further discussion.

The penetration of Chinese culture south of the Yangtze involved adaptations to a very different environment, largely an old plateau deeply dissected by relatively smooth running streams. Thus, water communication was a feature in the penetration of South China, and cultivation had to adapt itself to hillsides and occasional large flats liable to flooding. In place of millets, wheat, and beans, the typical crops of the north, rice, fruits, and tea play large parts in the south, doubtless the original home of tea, and probably of the orange, both of which have spread so far and have become elements of the equipment, not to say the cultural tradition, of Europe and the lands over which Europe has spread. In South China the Chinese culture has insinuated itself among older schemes of life, which persist in the rougher hill areas, but have given way to that of China in the lowlands, though Canton, the great southern centre, with its extremely dense population, is generally said to be Chinese with a difference. Whether that difference depends more on differences of breed of the people or on the fact that Canton has had many more contacts, by sea, with other lands than most of the central cities could be discussed in some detail. The importance of contacts in liberating initiative is very great indeed, and Canton is said to show initiative to a marked degree. The stream of penetration of Chinese culture into Szechwan—that is, south-westwards—seems to have diverged almost at the start from the penetration southwards, and in the Red Basin intensive cultivation of bottom lands is a great feature, but here, beneath great encircling hills cut by majestic river corridors, there have been relations with hill peoples, and with traders to and from Tibet, over what have been called the eaves of the world. Here, also, that valuable commercial commodity, salt, has been a source of wealth as an object of trade easily transportable. The north, the south, and Szechwan may thus be said to be three main constituents of China, the two last with Chinese culture introduced from the first and divergently adapted, the first with much cultural development *in situ*, but with some basic features that have probably been imported, perhaps from afar. The interrelations of regions may be studied from another point of view in China's case: we may note the entry of Western European ideas in the nineteenth century and the indifference, modified by occasional irritation, which seemed to be the marked feature of the situation for a number of years. The European interference, as much unconscious as it is conscious, at last led to events which broke down the traditional Chinese government, but the inertia of the great mass of the people steeped in the indigenous tradition of culture, and trying to pursue their work in spite of all the fighting around them, has been a marked feature of the present troubles, and has had no little bearing on the phenomenon of the maintenance of a good proportion of the Customs Revenue in spite of the long-continued disturbance. In this matter, again, it is probable that the reactions provoked by European interference may, in the long run, count for more than the European influence acting directly.

Spreads of culture modify enormously the relations between men and their environments, not only by importation of new ideas and by the process of adaptation which follows thereon, but also by the reactions they stimulate.

CHAPTER VII

CONCLUDING THOUGHTS

As the study of the relations between men and their environments proceeds we may hope that an advance in our philosophy of society may develop. The day for such an advance is not yet, we are as yet only feeling our way; physiology and psychology will need another long generation's advance to bring us to the desired point.

If we try to think of men's relations to their environments physiologically we may start from the fact that the body in doing work and in digesting food decomposes more complex compounds into simpler ones, for the most part, and so liberates energy, the surplus of which appears as heat and is dispersed. The dispersal of this surplus, over and above what is needed to keep the body at the optimum (98·4° F. more or less), is essential to health, the physiological processes are easily deranged or impeded by excessive heat. It is found that an atmosphere some 34°-38° F. below blood temperature permits the dispersal of surplus heat sufficiently quickly and without danger, and a temperature a little above 60° F. is for many types of men the most comfortable. But some physiological processes seem to have their optima at lower temperatures, and so colder spells now and again are valuable to the body provided it has the ability and the opportunity to manufacture extra heat by good food and vigorous exercise while the cold weather lasts. The general reaction of men to temperature strongly suggests that modern man had his first home in a region which then had a temperate climate, whatever may be its climate now. But the purpose of this discussion is not to speculate about man's first home; it is rather to draw attention to the specialisations which have resulted from his drifts from that home. He has drifted over equatorial Africa, and in that long process his body has adjusted itself to some extent to the trying continuous heat, in many districts made more trying still by moisture of the air which hinders evaporation of sweat, a process which in a dry, hot atmosphere gets rid of a good deal of the surplus heat. The large sweat glands with loose open pores, the soft skin with few dry layers, the rich supply of bloodvessels near the surface of the skin, the poverty and often the almost complete absence of body hair are all indications of the body's struggle to get rid of heat; the broadly open nostrils on a short flat nose and the everted lips are other indications in the same direction. We may say that the men of equatorial Africa, especially the true negroes, are organisms specialised to disperse heat as quickly as possible. The story of skin colour among them is a complex one hardly as yet satisfactorily unravelled, but it is at least noteworthy that the blackest of the black seem to live in regions with a long, dry, hot season, and that many inhabitants of the regions of damp heat have a more chocolate tone, the dark brown modified by blood colour connected with a frequently enormous development of skin bloodvessels. Some of the pigment is undoubtedly protective against excessive influence of sunlight, and especially of the violet and ultra-violet rays, an excess promoting histolysis or tissue-degeneration. There are other relations of pigment which cannot be discussed here.

If the inhabitant of equatorial Africa is adapted to a hot climate to some extent, he nevertheless suffers and finds it difficult to maintain regular hard work over long periods, and he often prefers to " live " after sunset and before the morning sun is hot, effacing himself when possible during the severest heat. It seems likely that, even with all the bodily arrangements for heat dispersal, the total amount that can be got rid of is much below what is possible in Europe, and the nervous system is apparently specially liable to suffer if heat dispersal is insufficient.

The men of Mongolia seem to illustrate adaptation on other lines. The fierce dry cold of winter there alternates with dry summer heat, which, however, is to some extent tempered by altitude, and it may be noted that not a few peoples of that region betake themselves with their flocks and herds to the heights for the hot season. The crucial difficulty is, therefore, extreme winter cold; there seems danger of undue heat dispersal at times, and the temperature of the atmosphere is often such as to endanger physiological processes in the extremities, while the nervous system may be benumbed by extreme cold. Among these people the bloodvessels of the skin are hidden deep down, and human skin when the bloodvessels have sunk into its depths typically looks yellow. Pores are in minimal numbers and dry layers of the surface skin are numerous and strong, and, as there are few pores, there is little skin-hair on the body. The skin is well adapted to prevent too great and too rapid loss of heat. The brown colour of the skin that often masks the yellow may be looked upon as largely a protection against sun glare and snow glare.

The conditions in Western Europe, in a sense intermediate between those of Mongolia and those of equatorial Africa, have permitted the retention of a certain amount of body-hair, the depigmentation of the skin, its moderate development of bloodvessels and sweat glands, and its moderate covering of dry skin layers. The skin not gorged with bloodvessels and sweat glands, nor, on the other hand, thickly covered with dry layers, seems to have a high degree of irritability which goes with the general alertness of mind, and the impatience, that are psychical characteristics of the European peoples. The contrast between this and, on the one hand, the patient endurance and solid continuance of many a Chinaman, a steadiness broken, however, at times by what may be called mental storms, or, on the other hand, the general easy-going cheerfulness of so many Africans, broken again by stormy episodes, is a matter worthy of much consideration in this context.

These few hints of physiological relation between men and environments might be extended almost without limit, and it seems probable that science will discover more and more of these relations and so help us to understand more deeply the variations of growth and activity in human races. It should be remembered that human breeds are by no means always completely adapted to their present environments, and the student who is interested in this may profitably study H. W. Bates' well-known account of the native of the Amazon, an immigrant from quite other climes who finds the moist heat very trying in the riverine forests in which he has taken refuge from enemies "until he pass away."

The general consideration of the social and psychological relations of men and their environments is even more subtle and elusive than that of the physiological relations. It is always of interest to ask whether they are such as to give either a small or a large proportion of men a surplus of vigour, resources, and equipment to promote initiative on a serious scale. An environment in which this is possible may be, either mainly by nature or largely by labour, a land of increment, and in such environments the societies may be primarily aristocratic or democratic according as the initiative is mainly confined to the few leaders or spread among the many; it need hardly be added that these terms are used etymologically and without political prejudice. A land of increment is obviously nearly always a land which includes suitable spots for habitation of at least its leader groups in climates suitable for healthy mental activity throughout the year. If the note of effort, with or without ultimate great increment, is definitely struck and remains the characteristic expression for a long time, it is well to describe the region in question as a land of effort and it is noteworthy that in many regions which have long been lands of effort, increment attained at last is often fairly widely distributed among the people as it is in Western Europe, where accordingly individual liberty is prized to an extent that is sometimes mocked at elsewhere. The dangers of the increment phase for the stability of societies of this kind are but too patent in the England of 1919-1929, an England faced with a sudden depreciation of its increment in several ways acting all at once, an England unfortunately too largely dependent on the efforts of the grandfathers of many of the figure-heads of the commercial world, figure-heads accustomed to look upon their increment as unassailable.

If the note of effort is struck with an almost painful intensity and large increment seems beyond hope in a region, such a region is a land of difficulty, and there are many. In fact, most regions have had to pass through this phase at some time or another. The land of difficulty is often keenly aware of the need for limiting its population, and it has done this typically by exporting its youths and maidens, as rural Wales does to the big English cities and the coalfields. Indeed, the export of thrifty, ambitious youth is a feature of such lands, and this is apt to diminish the value of the breed remaining behind; there is grave danger of breeding from the less fit in a land of difficulty. Moreover, there is some strain upon physiological balance due to poverty and imperfect feeding, and diseases consequent upon lack of that balance, and notably tuberculosis, are likely to take hold, especially of the more acquiescent of the population. It is in lands of difficulty that old modes of life survive, and thus that heritages, which crises in the wealthier centres might have obliterated, reappear to enrich the variety of social life, if sometimes also to trouble its peace. Those who are disposed to think that cold reason may be killing old faculties of apperception will be disposed to realise from this the high value of regions of difficulty to the life of mankind. It is specially noteworthy that in a region of difficulty much may be done by exchanges in kind and in services, though such exchanges may also be important in places of greater ease and prosperity. Wherever this occurs, and the use of money is relatively undeveloped, a fall in the value of money is a serious calamity, as it was for a number of regions of difficulty in 1918-1921.

There are regions in which the maintenance of healthy activity is difficult—that is, regions of difficulty where the main factor is physiological rather than social, and one might develop further this idea of considering regions according to the characteristic reactions between environment and men within them. But the matter is as yet too little developed for longer discussion.

Many other ways of looking at relations between men and environments present themselves to the mind. One might study culture contacts, for example, in language, when the stronger language, typically of the plains, pushes back the weaker one, typically into the valleys among the hills, unless, indeed, the downhill movement of people (from a region of difficulty to one of easier conditions) is great enough to counteract this. One might see under what conditions schemes of closer settlement displace those of sparser settlement, and *vice versa,* or one might study the typical forms of expression remaining, in spite of all obstacles, in regions of difficulty—art and architecture in regions of increment, poetry and oratory everywhere.

The lives of men are bound up with the little bit of earth that is given to each to love, and the student of geography must set himself to understand the links that bind him there, and not only these, but also the very different ones that bind him and his fellow men in all lands.

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LONDON: ERNEST BENN LIMITED
BOUVERIE HOUSE, FLEET ST. E.C.

First published 1928

MADE AND PRINTED IN GREAT BRITAIN BY
BILLING AND SONS, LTD., GUILDFORD AND ESHER

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OCEANS AND RIVERS

CHAPTER I

OCEANS AND RIVERS IN ANTIQUITY

THE Greek geographer Strabo, writing in the opening years of the Christian Era, was already able to refer his readers to a comprehensive Treatise on Oceans, that written by Posidonius some two centuries earlier. The general relationship of lands and oceans had, in Strabo's opinion, been correctly described at an even earlier date by the poet Homer, who said that the earth was entirely encompassed by the ocean. Homer, said Strabo, was justly regarded as the founder of geographical science, and he consequently went on to discuss the poet's views at some length. "Perception and experience," he writes, "alike inform us that the earth we inhabit [*i.e.*, the Old World] is an island: since whenever men have approached the termination of the land, the sea, which we designate Ocean, has been met with: and reason assures us of the similarity of those places which our senses have not been permitted to survey. For in the east the land occupied by the Indians, and in the west by the Iberians and Maurusians [Moors], is wholly encompassed, and so is the greater part on the south and north. And as to what yet remains unexplored by us, because navigators sailing from opposite points have not fallen in with each other, it is not much, as anyone may see who will compare the distances between those places with which we are already acquainted. Nor is it likely that the

Atlantic Ocean is divided into two seas by narrow isthmuses so as to prevent circumnavigation: how much more possible that it is confluent and uninterrupted. Those who have returned from an attempt to circumnavigate the earth do not say they have been prevented from continuing their voyage by any opposing continent, for the sea remained perfectly open, but for want of resolution, and the scarcity of provision. This theory, too, accords better with the ebb and flow of the ocean, for the phenomenon, both in the increase and diminution, is everywhere identical, or, at all events, has but little difference, as if produced by the agitation of one sea, and resulting from one cause."

The circumnavigation here referred to is that of the habitable world merely (conceived of as not extending as far south as the equator), and not of the globe. The latter feat, however, was not held to be impossible, for Strabo quotes his famous predecessor, Eratosthenes, as saying: "If the extent of the Atlantic Ocean were not an obstacle, we might easily pass by sea from Iberia to India, still keeping in the same parallel; the remaining portion of which parallel [*i.e.*, the land] . . . occupies more than a third of the whole circle; . . . the parallel drawn through Athens, on which we have measured the distances from India to Iberia, does not contain in the whole 200,000 stadia."

That the known world, from Spain to the Far East, occupied two-thirds of the circuit of the globe, or 240°, was the view held when China became known to the Greeks and Romans, but Ptolemy drastically reduced this estimate by 60° to 180°. The geographers of the Renaissance founded their work very largely on Ptolemy, but Christopher Columbus, eager to prove that he had reached the shores of Asia, took the older view of a narrow ocean. It is, indeed, just possible that he had read Strabo, of whose work a Latin version was published in 1469. Posidonius, who rightly held that the water surface of the globe forms a single confluent ocean, anticipated Ptolemy's estimate of the proportions of land and sea. Strabo quotes his opinion as follows: "He supposes that the length of the inhabited earth is about 70,000 stadia, being the half of the whole circle on which it is taken; so that (says he), starting from the west, one might, aided by continual east wind, reach India in as many thousand stadia." It may be remarked that Eratosthenes' measurement of the circumference of the earth was 252,000 stadia; hence, for him the parallel through Athens measured about 200,000 stadia, for Posidonius only 140,000. Since the length of the stadium varied at different times and in different places, the interpretation of this figure in terms of miles is uncertain. Ptolemy reckoned 60 miles to a degree, while according to Sacrobosco, Eratosthenes' measure was 56⅔ miles; the latter figure was adopted by Columbus, as giving the furthest longitudinal measure for his westward journey.

It was a very generally accepted view in ancient times that there was a second habitable land in the Southern Hemisphere, separated by the ocean from the known world. It is to this that Pliny refers when he writes: "Thus it appears that the seas which flow completely round the globe, and divide it, as it were, into two parts, exclude us from one part of it, as there is no way [*i.e.*, by land] open to it on either side." Crates, the earliest known globe-maker (*circ.* 150 B.C.), held that in each of the temperate zones there were two habitable areas, making four in all, so that the ocean had an equatorial and a meridional section. The "orb," the symbol of Empire, is simply Crates' globe.

The fact that the equatorial zone was, as the ancients supposed, "uninhabitable because of the heat," rendered the "other world" of the Southern Hemisphere not only unknown, but unknowable. Hence it lay outside the scope of the ordinary geographical treatise, and of the "world chart" in common use; the latter showed merely the Œcumene and the surrounding sea.

The Ionian School of Geographers, as represented by Hecatæus of Miletus, schematized this map, drawing it in circular shape so that the ocean formed a uniform ring about the land surface. This Herodotus derides in the following passage: "For my part, I cannot but laugh when I see numbers of persons drawing maps of the world without having any reason to guide them: making, as they do, the ocean stream to run all round the earth, and the earth itself to be an exact circle, as if described by a pair of compasses, with Europe and Asia just of the same size."

Later classical writers, from Eratosthenes onwards, emphasized the fact that the dimensions of the habitable world were greater from west to east than from north to south, but the circular map, agreeing as it did with popular concepts derived from the circular horizon, continued in use. It was the map taken over from the classical world by the Christian writers of the Dark Ages, who adapted it to the cosmogenical ideas which they obtained from the Sacred Scriptures. The Arabs accepted and carried on the Greek scientific teaching as to the spherical shape of the earth, and their point of view is revealed in the following quotation from Masoudi's delightfully named *Meadows of Gold*—actually a geographical compendium. He writes: "The configuration of the sea has aroused much discussion. The greater number of the ancient philosophers of India, and the sages of Greece, except those who have embraced revelation, consider that the sea follows the spherical movement [*i.e.*, shape] of the earth, and they prove it by a number of arguments. Thus, when one goes abroad, first the land, then the mountains disappear, the summits last. . . ."

The circular world map, or Mappa Mundi of the Medieval Period, was oriented with the east at the top, and there the cartographer usually placed the Earthly Paradise. From Paradise, in accordance with the Bible narrative, four mighty rivers were shown gushing out to water the land; these were the Euphrates and Tigris, the Gihon and the Phison. Since the Gihon was said to embrace Ethiopia, it was identified with the Nile, while the Phison was held to be one of the great rivers of India. A difficulty arose as to how the Nile reached Africa from the Far East, and an alternative locality for Paradise was in the Dark Continent itself, perched on a high mountain upon the Equinoctial Line, and safe out of reach of Noah's Flood.

It is in harmony with the arid climate of the Semitic lands, where rivers are so necessary for irrigation purposes, that the Semitic Paradise should be pictured as the source of life-giving waters. It is from the Bible that we have the concept of a river as " watering " a country, an expression that became a commonplace of geographical terminology, although in countries with a moist climate, such as that of England, the function of rivers is to drain the land.

The River Nile was, of all the rivers familiar to classical writers, the most obviously important. Hence its sources, its feeders, and its annual floods, were matters that were very generally discussed among philosophers, as indeed they have been down to the present day. The Egyptians themselves, to whom the river was sacred, gave mystic explanations of its phenomena; the Greeks sought for scientific ones. From Herodotus we learn that one suggestion, which he considers absurd, was that the Etesian winds, blowing in summer, prevented the river waters from discharging into the Mediterranean Sea, whence the floods resulted. A second theory, which he also dismisses, was " That the Nile acts so strangely because it flows from the Ocean, and the Ocean flows all round the earth." " For my part," comments Herodotus, " I know of no river called Ocean, and I think that Homer, or one of the earlier poets, invented the name, and introduced it into his poetry." A third explanation, repeated down to the present day, was that the floods were caused by the melting of the snows in Libya, while Herodotus himself offered the suggestion that the river was reduced during part of the year by evaporation, and then resumed its normal flow. Strabo, writing over four centuries later, gives the correct explanation—namely, that the floods are caused by the heavy summer rains in Abyssinia.

Since the sources and upper course of the Nile were even more mysterious than its floods, these were fantastically mapped right down to the nineteenth century. The Arabs looked on the Senegal River as the mouth of the so-called Western Nile, which left the Egyptian Nile somewhere in the Sudan, but the maps of the Renaissance Geographers were usually based on the account given in Pliny's *Natural History*, which was partly derived from the writings of King Juba of Mauretania. This account is as follows: " [The Nile] rises in a mountain of Lower Mauretania, not far from the [Atlantic] Ocean; immediately after which it forms a lake . . . which bears the name of Nilides, . . . a crocodile . . . was brought from thence to show that this really is the Nile. . . . In addition to these facts, it has been observed that the waters of the Nile rise in the same proportion in which the snows and rains of Mauretania increase. Pouring forth from this lake, the river disdains to flow through arid and sandy deserts, and for a distance of several days' journey conceals itself; after which it bursts forth at another lake of greater magnitude in the country of the Massæsyli, a people of Mauretania Cæsarienses, and thence casts a glance around, as it were, upon the communities of men in its vicinity. . . . It then buries itself once again in the sands of the desert, and remains concealed for a distance of twenty days' journey, till it has reached the confines of Ethiopia. Here, when it has once more become sensible of the presence of men, it again emerges, at the same source, in all probability, to which writers have given the name of Niger, or

Black. After this, forming the boundary line between Africa and Ethiopia, its banks, though not immediately peopled by men, are the resort of numbers of wild beasts and animals of various kinds. Giving birth in its course to dense forests of trees, it travels through the middle of Ethiopia under the name Astapus. . . ." The Astapus was one of the rivers that flowed round the Island of Meroë, and is to be identified with the Blue Nile. From this point the river was well known.

It is a curious fact that the old writers, with but few exceptions, never realized the essential relation between the river and the slope of the ground, which determines its course; maps, of course, then gave no clue to relative levels, and it was thought quite natural that a river should divide and flow in opposite directions, as the Nile indeed did in the delta section. In Greece itself the disappearance of a river into a limestone cavern and its reappearance elsewhere was not uncommon, and hence the Greeks naturally supposed that the rivers of North Africa, which actually lose themselves in the sand by evaporation and seepage, had burrowed underground, and were to be met with again in Ethiopia (the Sudan). In this connection Pliny remarks in good faith: " Some rivers, from a real hatred of the sea, pass under it."

The modern science of Hydrography had made little progress until the nineteenth century, although particular problems had earlier forced themselves upon men's attention in connection with the improvement of waterways and the construction of canals for navigation purposes.

CHAPTER II

NATURAL WATERS: THE RIVER IN MAKING

It is an old paradox that all the rivers run into the sea, and yet the sea is never full: even granted a constant re-evaporation, it yet remains a puzzle that a perfect balance is always maintained. Actually, however, the rate and amount of evaporation are partly conditioned by the relative humidity of the air, which is also one of the factors influencing precipitation, so that there is a relationship between the addition and removal of water to and from the sea, which is not at first apparent.

Of all the rain that falls on the land, it has been calculated that rather more than a quarter—namely, 28 per cent.—is sooner or later carried by rivers to the ocean, to be brought back in invisible form by moisture-bearing winds. Thus 28 per cent. of the total rainfall is derived from the ocean waters, while the remaining 72 per cent. results from evaporation and recondensation over the lands themselves.

The question, Why is the sea salt? has not been completely answered. It is obvious that the rivers will wash out of the soil the soluble constituents of the earth's crust, and will carry them down to the sea, there to accumulate, but whereas the most important dissolved substance carried by rivers is calcium carbonate, the principal dissolved substance in the sea is common salt, or sodium chloride. That the calcium carbonate should disappear is to be expected: it is removed from solution by various organisms, to form the shells of molluscs, the skeletons of coral polyps, the tests of formanifera, and so on. As these organisms die, their calcareous parts accumulate on the sea floor as bottom deposits, and these calcareous deposits will eventually be hardened and compacted into the limestone rocks of a future geological age. Organisms do not remove common salt from the water, so that the minute amounts which the rivers carry, about 0·013 parts per thousand, have been accumulating throughout the ages in the oceans. This fact has been utilized to calculate the age of the earth since it was cool enough for the oceans to form, but it is possible that their waters contained an initial percentage of dissolved salts.

Although the two salts that have been named—calcium carbonate and sodium chloride—form the most important dissolved constituents of river water and sea water respectively, each is associated with a large number of other salts in smaller quantities. This is ascertained by an analysis of the dry matter obtained by the evaporation of large volumes of completely filtered water. Among these secondary salts, the sulphate of calcium, and the carbonate, sulphate and chloride of magnesium take an important place. A remarkable fact about sea salt—*i.e.*, the dry matter obtained by evaporation of sea water—is its uniformity of composition, even when obtained from widely differing seas. There are only about 7 parts of sea salt per thousand in the waters of the Baltic, 35 parts per thousand in the Atlantic Ocean, and 40 parts per thousand in the Red Sea; yet as the table on p. 16 shows, the proportion of the different chemical substances present varies only by a fraction per cent.

It will be noticed that the Indian Ocean has only one-quarter the normal (very small) percentage of carbonate among its salts, while the Red Sea has only one-tenth. This is due to the fact that these are tropical waters, where there is a high activity of coral-

PERCENTAGE ANALYSIS OF SOLID MATTER IN SEA WATER
(Johnstone.)

	Atlantic Ocean.	Baltic Sea.	Mediterranean Sea.	Red Sea.	Indian Ocean.	All Observations.
Chlorine Ions (Cl)	55·19	55·01	55·53	55·60	55·41	55·29
Bromine Ions (Br)	0·18	0·13	0·18	0·13	0·13	0·19
Sulphate Ions (SO_4) ...	7·91	8·00	7·74	7·65	7·79	7·69
Carbonate Ions (CO_3) ...	0·21	0·14	0·19	0·02	0·05	0·21
Sodium Ions (Na)	30·26	30·47	30·37	30·81	30·89	30·59
Potassium Ions (K)	1·11	0·96	1·09	0·97	0·85	1·11
Rubidium Ions (Rb)	—	0·04	—	0·04	0·03	—
Calcium Ions (Ca)	1·24	1·67	1·26	0·89	1·16	1·20
Magnesium Ions (Mg) ...	3·90	3·53	3·64	3·87	3·67	3·73
Other Ions ...	—	0·05	—	0.02	0·02	—

reef building organisms: the same waters are poorest in calcium. A point to point collection of specimens of sea water would reveal many slight variations of this character, especially where living organisms are numerous, or where a large river was bringing river salts in unusual quantity. The *generally* uniform composition of sea salt is, however, due to the fact that it is an end-product—*i.e.*, the product necessarily obtained when the complete range of dissolved salts brought down by rivers is subjected for an indefinite time to the comparatively uniform physical and organic conditions obtaining in the ocean.

River salt, in contrast to sea salt, necessarily reveals great variety on analysis, because each river flows across, and is fed by springs from, a region of individual characteristics as regards rock composition. The differences are made very apparent if the river discharges into a lake or inland sea which has no outlet to the ocean. The accumulated salts consist occasionally of almost pure carbonate of soda, or of sulphate of lime or of sulphate of soda. The salt encrustations round a saline lake may differ completely from the mother-liquor of the lake itself, for once a certain degree of concentration is reached, the least soluble will be precipitated out while the more soluble will remain in solution. If, for example, there are sufficient carbonate ions present, all the calcium and magnesium present will be precipitated as carbonates. If there are insufficient carbonate ions present to bring down all the calcium and magnesium, but some sulphate ions are present, then calcium sulphate will be precipitated : only in the rare absence of calcium will magnesium sulphate be found, while only in the still rarer absence of both calcium and magnesium will the carbonate ions unite with any sodium that is present to produce sodium carbonate, or common soda.

The following percentage analyses of the solid matter in lake, spring, and river waters (after Clark and Irwin) (see p. 18) illustrate the points that have been raised.

The Hot Spring at Tiberias, analyzed in the last column, has a temperature of 140° Fahr., and is strongly impregnated with common salt. It contains nearly 30 parts of solid matter to every thousand parts of water, whereas the average river has about 1 part of solid matter to ten thousand parts of water. This is one of several springs that make the Jordan unusually rich in common salt, and in magnesium and calcium chloride, which consequently accumulate in the Dead Sea. The Sea of Galilee, with a constant

	Rio Grande of New Mexico.	Snake River, Idaho	San Joaquin, California.	River Jordan at Jericho.	Average of all Rivers.	Hot Spring at Tiberias.
CO_3	1·54	26·31	18·43	14·2	35·15	—
SO_4	43·73	13·36	17·41	2·1	12·14	1·7
Cl	22·56	17·01	20·62	45·4	5·68	61·0
NO_3	—	—	0·54	—	0·90	—
Ca	13·43	16·20	10·13	11·7	20·39	10·0
Mg	3·62	3·64	4·82	5·2	3·41	2·7
Na	14·02	15·38	15·81	19·8	5·79	23·0
K	0·77	8·10	1·08	1·1	2·12	
$(FeAl)_2O_3$ ...	0·33	—	1·78	—	2·75	—
SiO_2	—	—	9·38	—	11·67	—

flow of water in and out of it, has only half a part of solid matter for every thousand parts of water, whereas the surface waters of the Dead Sea have 192 parts per thousand, and the waters 1,000 feet from the surface contain 259 parts of solid per thousand. The deeper parts of the Dead Sea are one and a quarter times as heavy as pure water, volume for volume.

The saline constituents of ordinary rivers, minute in quantity as they normally are, take on great importance when the water is used for irrigation. The soil over which the irrigation water is distributed, or into which the excess water is drained, becomes the theatre of deposit of the salts, which slowly accumulate, and the ground may become saline and entirely ruined in the process.

Springs are a major source of supply of salts to rivers, and hot springs, such as that of Tiberias, are very rich in salts. Such springs are, however, the less common type, being of a deep-seated character. Ordinary springs restore to external circulation waters that have not gone far, or remained long, below the ground. As is well known, where there is a sandy or gravel soil, or a chalk or limestone subsoil, the ground rapidly dries after heavy rain, whereas a clay surface remains water-logged until evaporation has dried it. Sand and gravel, composed of coarse, loose fragments, allow water to flow freely through them. Clay, which is composed of very fine particles, differs in chemical composition and physical properties from sand and gravel; its particles hold water firmly and do not allow it to flow. Hence clay is termed impermeable to ground water—it is a water-holding soil—while sand and gravel are freely permeable. Compacted rocks, such as chalk and sandstone, may be either minutely fissured, or porous, when they, too, are permeable to water. Rocks, such as granite, usually display irregular joints and fissures at irregular intervals, down which water can pass, and so are locally permeable, while limestone which has been long exposed to the action of ground water has its numerous joints and fissures so enlarged that it becomes freely permeable, and is, indeed, often a major source of supply of springs of large volume.

It is clear that water can only flow through a permeable rock if there is a means of exit at a lower level: a bed of sand lying in a basin-shaped formation of clay could become completely water-logged where the rainfall was heavy, and so present the anomaly of a boggy surface on sand. In general, however, the water sinking into a permeable rock is checked at a certain depth by an impermeable layer, and flows along the lowest line of the latter as it would flow down a valley, eventually issuing as a spring on some hillside, below the level at which it entered the ground. There is often a considerable head of water, measured upwards from the impermeable base, filling the interstices, pores, and fissures of the permeable rock, this head being determined by the normal rainfall of the region, and the rate at which the water can move towards the springs. The upper surface of the underground water is termed the water-table, and is a surface sloping at first gently, and at last fairly rapidly, towards the effluents. This fact can be determined by comparing the levels to which the water rises in wells sunk below the water-table. The removal of water by continuous pumping on a large scale for a town water-supply may lower the water-table and cause springs and small wells to dry up, since it increases the rate of flow upon which the height of the water-table partly depends.

The resistance to flow offered by a permeable bed of rock varies with the size of the interstices through which the water has to pass. Movements through gravel take place so freely that the water forms, in effect, an underground river, and hence an extensive bed of this character yields an unfailing water-supply. Gravel is, however, of very local distribution, being most abundant on the margin of areas that have been heavily glaciated. Sand dunes, owing to their extreme permeability, are also useful sources of spring or well water. In the Sahara, "dune-foot" springs are not uncommon, while there are many wells sunk in the marginal dunes of Holland. In some of these wells the water, while remaining perfectly fresh, rises and falls with the tide. This is due to the pressure of the heavier salt water, which flows under the lighter fresh water, without contaminating it.

The danger of contamination, and the uncertainty of well-sinking, alike become greater when the underground water is contained in large, and sometimes independent, fissures, instead of uniformly penetrating the rock. In limestone regions especially, the water issuing from a spring, or tapped by a well, may have travelled by an underground channel direct from a cave or from a swallow-hole containing refuse or offensive organic matter. It is only when water sinks deep enough to pass through fine interstices or fissures from which air is excluded that it is filtered and purified, and becomes fit for domestic use. Chemical impurities, such as calcium carbonate, are, of course, increasingly present where the underground journey has been a long one, and especially in chalk or limestone regions.

Hot mineral springs, charged sometimes with gases as well as salts, are very commonly associated with a major fault line—that is to say, a line marking the position of a large scale crustal fracture, the fracture having been accompanied by displacement of the rock strata. Such a fracture line offers a means of escape for deep-seated underground waters, the high temperature of which is witness to the depth from which they have come. A fault line may also be marked by a line of springs of normal temperature, for a down-sloping bed of permeable rock, which water enters freely, may be blocked at the lower end by a face of impermeable rock which has been brought into position by the fault displacement. Hydrostatic pressure will then force the water upwards along the surface of the fault plane.

A region of actual or of recent volcanic activity is also the scene very usually of hot mineral springs. Such springs, however, may bring to the surface water that has not originated at the surface. Water enters very largely into the composition of the deep-seated magmas underlying the earth's crust, and it is this water which is released when volcanic action brings the magmas near to or above the surface. Hot springs of this character contain sulphur, borax, alum, and other chemical substances which they could not derive from the surface rocks, and it must be concluded that some, although not necessarily all, of their water is plutonic.

CHAPTER III

THE RIVER IN BEING

Wherever the ground-level dips below the water-table, there is either a standing or a flowing body of water—*i.e.*, a lake or a river must be found, according to the surface configuration. Whenever, through continued drought, the water-table is lowered below that of such a river or lake bed, the water will seep away underground, and if this flow takes place faster than the delivery of fresh supplies of water from higher levels, the river or lake may dwindle quite away. In some parts of the world—for example, in the Kalahari and Sahara—the existence of a network of dry river beds point to an almost permanent lowering of the water-table, possibly owing to secular climatic change. Such dry water-courses are frequently clothed with vegetation when surrounding areas are bare, showing that the underground water is reaching the surface soil through capillarity. Shallow wells sunk in the old river bed will often give an abundant water supply, and it is a fallacy to suppose that areas without visible surface water are uninhabitable. Exceptional rains will refill such a dry river bed; every year or two the local winter rain-storms of the Arabian Desert, east of the Nile, cause one of the larger wadies to come down in flood, sometimes so suddenly as to sweep away grazing sheep and camels; in 1894, the broad, gravel bed of the Malopo (dry) River in Bechuanaland was filled with water from bank to bank. The presence of air in the insterstices of the dry soil is a factor in promoting the appearance of such a temporary river above the surface of the water-table, but eventually the water displaces the air and seeps away.

From a practical standpoint, whether it is required to utilize a river for domestic water, for navigation, for irrigation, or for power, or whether it is merely required to prevent damage by flood, the essential point is to know the normal discharge, or volume of flow of the river, and to know, further, the deviations from the normal that are to be expected from season to season, and from year to year. Such information can be obtained by means of a prolonged and costly series of careful direct measurements, but systematic observations on a uniform plan can only be undertaken by a Government Department (as in the United States) and consequently potamological data are relatively few and unco-ordinated. Engineers must, as a rule, therefore, make an estimate of the discharge from a few *ad hoc* observations, combined with theoretical considerations. As most civilized countries have a Meteorological Service, rainfall statistics and rainfall maps are fairly generally available, and the most practical method of attacking the problem is to establish the relation between rainfall and run-off.

It is the first essential to know accurately the area from which a river is fed, whether by rain or springs. In the table on p. 24 (after Bludau), the length of each of the chief rivers of the world and the area of its catchment-basin is given. It will be noticed that the arrangement of the rivers in order of length does not coincide with their arrangement in order of the size of the area drained.

It is obvious that there can be no simple and universal numerical relationship between rainfall and run-off. Of the rain that falls, a proportion is immediately re-evaporated, this proportion varying with the temperature, etc., of the air. A proportion sinks into the surface soil, where it is utilized by plants, and returned to the air by transpiration; the amount concerned will vary with the seasonal variation in plant activity. A further proportion of the rain will sink

Name.	*Length (Kilometres).*	*Area of Basin (Square Kilometres).*
Europe:		
Volga	3,570	1,400,000
Danube	2,850	817,000
Rhine	1,326	224,000
Asia:		
Ob	5,200	2,915,000
Yensei	5,200	2,510,000
Yangtse-kiang	5,200	1,775,000
Lena	4,600	2,320,000
Amur	4,480	2,010,000
Hwang-ho	4,100	980,000
Indus	3,180	960,000
Ganges	3,000	1,060,000
Africa:		
Nile	6,500	2,803,000
Congo	4,200	3,690,000
Niger	4,160	2,092,000
Zambesi	2,660	1,330,000
Orange	1,860	960,000
America:		
Mississippi	6,530	3,248,000
Amazon	5,300	7,050,000
La Plata	4,700	3,104,000
St. Lawrence	3,800	1,248,000
Mackenzie	3,700	1,660,000
Nelson	2,400	1,080,000
Orinoco	2,220	944,000

more deeply into the ground, and the greater part of this water will reach the water-table and at a later date re-emerge from a spring. The springs will eventually swell the total run-off, although the sub-surface structure may lead the ground water into the basin of a neighbouring river. A certain proportion of the ground water will return to the surface by capillarity during dry or hot weather, and so increases the proportion of the original rainfall that is restored to the air by evaporation. There is the further fact to be considered that a steeply sloping surface promotes immediate rapid run-off, and so reduces the loss by evaporation and infiltration. Again, a very porous soil allows the water to sink rapidly below the surface, which again reduces the loss by surface evaporation, and eventually increases the co-efficient of run-off.

The measurement of the actual run-off, as given by the volume of water carried by the river past a certain point, is a difficult matter. The factors involved are the area of cross-section of the water, and its rate of flow, or current velocity. Now, the current velocity is a function, not only of the slope of the water surface, but of the volume of water flowing, and so varies according as the river is at a high stage or low stage. The cross-section of the water, or area contained within what is called the wet perimeter, is also variable according to the stage of the river. Hence the gauging must be continuous if an approximately accurate result is required. Two further complications occur: the current is not constant from point to point of the cross-section, and consequently a large number of measurements must be made with the current meter at different depths, and at different distances from the banks, to get at the mean value. Further, not only does the area embraced by the wet perimeter vary according to the stage of the river, but a river of torrential character is constantly eroding its bed, and so changing its shape and depth, while a river overloaded with silt alters the shape of its bed by deposition.

Supposing a series of observations to be made in which all these points have been allowed for, then the product of the mean velocity and the mean cross-section gives the discharge of the river in cubic feet or cubic mètres per second. The "discharge curve" of a river is obtained by plotting the heights above low stage (*i.e.*, mean minimum level) as abscissæ, and the corresponding volumes of flow as co-ordinates. The total volume of rain falling on the river basin, divided by the surface area of the basin, gives P, the pluviometric index. The total discharge of the river at its mouth, divided by the surface area of the basin, gives the index of discharge, D. The relations of rainfall to run-off can be conveniently studied by means of curves, the corresponding values of P and D being plotted as abscissæ and co-ordinates respectively. A comparative study of such curves, which differ considerably for different localities, allows some general conclusions to be drawn, as, for example, that in cool, temperate climates the run-off approaches zero when the rainfall is only 10 inches, while in sub-tropical regions 20 inches of rain, and in torrid regions 40 inches of rain, is necessary to insure flowing rivers. Moreover, the run-off increases at first only slowly, but finally very rapidly, with increase of rainfall. Thus, for example, an increase of rainfall from 45 to 50 inches has a much greater effect than an increase from 15 to 20 inches.

A second method of graphical study of the relation D : P is to map the values of the two co-efficients by means of isometric lines, and compare the maps from point to point. On a gently sloping plain, when the rain falls during a very hot summer, the run-off may be as low as 10 per cent. of the precipitation, while on a cool plain, with an impermeable subsoil, it may be over 70 per cent. In wet mountain regions a run-off of 80 per cent. is normal, while figures as high as 90 to 95 per cent. are not unknown. Where the precipitation occurs as snow, there is very little infiltration and very little evaporation, and when, in addition, the slopes are steep and the soil bare, the high coefficient of run-off is explained. A single heavy down-pour of rain, or a sudden rise of temperature of several degrees, may transform a mountain stream in an hour from a mere rill into a dangerous torrent.

The question of soil cover is an important one; there is little doubt that the run-off from a region with forest growth is more uniform than the run-off from a region where the forests have been destroyed; there is no evidence, however, that the destruction of the forest diminishes the total run-off; the reverse, indeed, being probably the case. Furthermore, it is probable that the removal of any vegetational carpet would have a similar effect. Careful observations show that a forest influences the climatic elements in the same way as a sheet of water, but to a much less degree, and more locally; the diurnal and annual range of temperature is reduced and the relative atmospheric humidity is slightly increased. The forest affects the run-off, however, mainly through the medium of soil conservation. The roots of the trees serve to bind the soil, while the decayed vegetable matter increases its depth; the consequence is that the rainfall is held in the soil, instead of running off the surface immediately. Any other complete vegetable carpet would have the same effect, while if the surface slopes were so gentle that there was no danger of soil denudation upon the removal of the vegetation, then the effect of such removal would be negligible.

The table shown on p. 28 (after Schmidt) gives the mean percentage run-off for some important European rivers, arranged according to the topography of their basins. The table brings out the fact that slope is an important factor, but that it may be masked by other factors; for example, the rivers of the west of Europe tend to have a larger percentage run-off than those that lie further east, owing to the less evaporation and the greater winter rainfall.

The figure showing the mean annual value of the run-off is, for practical purposes, less valuable than the

Name.	*Rainfall in mm.*	*Percentage Run-off.*
Lowland :		
Lower Oder	608	24·0
Lower Elbe	601	26·3
Lower Weser	717	37·5
Lower Rhine	830	44·2
Lower Danube	749	32·5
Ems	729	37·8
Upland :		
Oder (Ratibor)	836	37·2
Elbe (Brandeis)	762	31·2
Rhine (above Cologne)	911	52·6
Moselle	334	43·7
Danube (Ulm)	793	42·1
Mountain :		
Reuss	1,370	76·0
Inn (Innsbruck)	1,365	72·5
Enns	1,450	48·0
Lech	1,169	66·7
Rhine (Constance)	1,100	72·3

monthly or daily figures showing the seasonal regimen of the river. The topographical and geological conditions remaining constant, the variations from month to month are due, in the first instance, to climatic factors —precipitation, evaporation, frost, snow-melting—and to a less degree to seasonal changes of vegetation. The reduction of run-off due to the moisture used by plants is naturally greatest in the hot season, and the general relationships are displayed in the table shown on p. 29 (after Ule).

Four leading types of river regimen (or seasonal volume) may be distinguished :

1. Regimens determined by seasonal precipitation, where the temperature is evenly distributed.

Saale River.	Winter mm.	Spring mm.	Summer mm.	Autumn mm.
1. Precipitation	108	144	216	146
2. Loss { by Evaporation ...	45	96	112	66
by Vegetation ...	—	21	40	10
3. Storing { as Ground-water	3	4	47	37
as Snow ...	35	10	—	2
4. Theoretical Run-off =1—(2+3)	25	13	17	31
5. Actual Run-off	48	60	28	32
6. Deficit (5−4) covered by Stored Water of previous Seasons	23	47	11	1

2. Regimens determined by temperature change, where the rainfall is evenly distributed.

3. Regimens determined by snow-melting.

4. Regimens determined by seasonal precipitation combined with seasonal temperature change, (*a*) the rainfall occurring during the hot season, (*b*) the rainfall occurring during the cold season.

Mixed regimens are, naturally, very common, since most large river basins include more than one climatic region.

Rivers of the first type, with a discharge which reflects the seasonal rainfall, occur within the tropics. Evaporation goes on steadily during the dry season, and has its maximum effect during the hot season that usually immediately precedes the rains; the run-off is then a minimum. The rains set in suddenly, so that the stream beds often fill more rapidly than the water can be carried off, with resulting danger to culverts and bridges. Such is the regimen of the Upper Niger, which is at its lowest in May and early June, but rises rapidly during June, July, and August, to a maximum level in September, beginning to fall again in October.

The fact that this is also the regimen of the Lower Nile gave colour to the belief, held alike by classical and Arab geographers, that the Niger was a western branch of the Nile.

The Thames is a typical river with the second regimen. Throughout its basin the rainfall is round about 2 to 2½ inches a month, and consequently its level is lowest in summer, when evaporation is greatest. Any abnormal rate of delivery of water to the Thames —*e.g.*, heavy rains following prolonged frost, or heavy rains during an unusually cool summer—may cause floods.

The Seine has a somewhat similar regimen. It gathers its waters from a wide semicircle to the east and south of Paris, and is at its highest during winter and spring, falling in summer owing to evaporation. Of its affluents, the Yonne comes from the Morvan upland, a region of steep slopes and impermeable rocks, snow-covered in winter. It is the Yonne, therefore, that is likely to come down in strong flood, especially in spring, and if this flood chances to coincide with unusual rains in the east, so that the Upper Seine and Marne are also high, Paris is threatened with inundation.

Rivers of the third type, fed mainly from snow-fields —*e.g.*, the Alpine rivers—begin to fall in level in the late autumn, and continue to dwindle until they reach their minimum in spring; they normally become swollen and torrential during the hot season, while an unseasonable thaw, such as that due to a fœhn wind, may cause a sudden flood. A modification of this type occurs when a river is fed only from the lower snow slopes which are completely melted early in each year. Such a river is very full in the spring and early summer, but it is then rapidly reduced by summer evaporation.

As regards the regimen of the fourth type, where both temperature and precipitation are markedly seasonal, the position is most serious where the hot season and the season of drought coincide, as they do in the Mediterranean Basin, and in areas of similar climate. The volume of water discharged during winter and spring contrasts very markedly with that discharged during summer and autumn, the smaller rivers being torrents at the one season, and often mere threads of water or chains of pools at the other.

The combination of hot, wet summer and cool, dry winter is met with in the so-called "continental climate" of the temperate zone, as, for example, in Central Russia. Here the onset of the cold season is marked by snowfall, this snow lying on the ground until spring. During March and April rapid snow-melting causes a torrential flow of the swollen rivers, while the summer rains suffice to keep the river at mean level during that season, in spite of the great evaporation. In the dry, hot weeks of early autumn the water-level begins to fall, and reaches a minimum during the frost and snow-bound winter months. Abnormalities occur when such rivers flow long distances from south to north, as they do in Siberia. Under such circumstances, the snow melts first in the southern or upper part of the basin, while the lower river, and the country all around it, is frozen; the result is widespread flooding, since the water cannot flow away to the sea.

The Rhine illustrates the characteristics of a mixed regimen. It first collects the drainage of the Swiss Alps by numerous affluents before crossing the frontier at Basle. Hence this section has a minimum flow in January and February, and rises to a maximum in June and July, the difference of level at Basle being about 5 feet. The Neckar, the Main, and still more markedly the Moselle, show a summer minimum during the season of greatest evaporation, with a tendency to a slight spring rise above the already high winter level owing to snow melting on the hills. Consequently, when the Rhine has received these tributaries, the total volume of water flowing past Coblenz is very uniform all through the year, the lowest stage being in October. During this month, the water delivered from the Alps is falling off, while the water-rise in the tributaries from the uplands is hardly established. Lower down the Rhine, where it moves slowly across the Dutch plains, the total run-off diminishes, and summer evaporation makes itself felt.

A model for the complete study of a river is afforded by Captain (now Sir Henry) Lyons' monograph on the Nile, *The Physiography of the Nile and its Basin*. Such a work involves a review of topographical and geological conditions, and a critical survey of all available climatic data. Gauge readings of the level of the Nile go back to the remotest times, as far as Egypt is concerned, while there are long series of observations available, made in modern times, for various points on the upper basin of the river, where alone rain falls. Unfortunately, the problem of predicting the occurrence of high and low Nile has not yet been solved, but Lyons' summing-up of the explanation of the floods is worth quoting in full, illustrating, as it does, some of the general principles that have already been laid down.

"One of the two principal factors in the Nile supply . . . is the Albert Lake and the rainfall on the plateau immediately to the north of it; the other, and by far the more important, is the rainfall on the Abyssinian tableland which supplies the Blue Nile and Atbara. From these pours down the Nile flood in July, August, September, and October, while in most years the Blue Nile flows throughout the year, though its volume after January is small. . . . Abyssinia, after centuries of arrested development, appears now to be advancing rapidly, and with the cessation of civil war . . . a large increase of population must take place. While it is not likely that any change of river regimen will occur in the immediate future, it is impossible not to be struck by the frequent mention by travellers of deforestation in the neighbourhood of the larger settlements, and at a future period it may be that this may proceed far enough to bring about the results which have been experienced in other countries, namely, more rapid rise and fall of floods, their greater range, and a greater removal of detritus from the mountain tract to be deposited in the first reach of moderate slope, that is, the river bends on the Sudan plains. . . .

" When we notice how very moderate the rainfall is on the Sudan plains to the north of lat. 9° N., the importance of this [Abyssinian] tableland, rising to 2,000 and 3,000 metres above sea-level, is evident, for without it to cause the westerly air currents to rise, and thereby condense their moisture in form of rain, the Nile would end in the northern desert of the Sudan by its waters being diminished by evaporation and finally sinking beneath the surface and depositing its load of sediment as an alluvial fan, like the Khor el Gash and many other rivers of Northern Africa. . . .

" It is the regularity of the annual-rise and fall, and variation of the volume of the Nile flood from year to year, which may be said to be the most striking features of the Nile regimen. . . . The narrow margin, 4 cubits, or about 2 metres, which exists between a bad and good Nile, has been noticed by all writers on Egypt and the Nile from the time of Herodotus. This small range of the flood-level and the great regularity with which the rise takes place from year to year, with a difference of a few days only, are features of the regimen of the river, the cause of which is not difficult to trace in the geography and the climate of the Blue Nile basin. The first is due, partly, to the long 1,500 kilometres reach from Berber northwards without a single tributary, in which the sudden rises in the higher reaches are gradually lost in the steady flood rise, and partly because all the tributary streams take their rise on the Abyssinian plateau and are fed by a short, heavy rainfall of about 1,000 millimetres in four months, as an average value. The majority of large rivers are supplied by a network of tributary streams which extend far throughout the basin where, probably, different climatic conditions or geographical features, such as mountain ranges, affect the rainfall so as to produce the greatest precipitation at different seasons in different parts of the basin. Thus it often happens that the rise of a great river is due normally to rainfall over a portion only of its basin, and when exceptional rainfall takes place over other portions at the same season, different tributaries, which usually rise in flood successively, will be in flood at the same time, and so cause destructive inundations." Such, in fact, is the explanation of the great floods which have from time to time overwhelmed the lower Mississippi valley, when the danger is magnified by the fact that the river has been confined by partly artificial levees, which are unable to sustain the unusual pressure upon them.

CHAPTER IV

THE RIVER IN USE

A RIVER system, down to its smallest tributary, functions definitely as an organic whole, and is as definitely a unit as is a tree down to its smallest twig. This is an obvious truism, but one that has in practice been ignored, so that a particular river may be parcelled out under the control of a score of public bodies, each one without power over the waters that enter its administrative area, and without responsibility for those waters when they leave it. Yet the most ancient civilizations were based on the use of rivers: the Nile provided alike the bond of intercourse—the highway—and the fertilizing waters for the fields. A study of the history alike of Egypt and of Babylon reveals that unified control, efficient organization, concerted action, lay at the root of this successful use of the river, and that because of the qualities thus bred in the riparian peoples, they became not merely wealthy but great.

The dangers and difficulties that arise from the neglect of the principle of the unity of a river can be illustrated very simply. The efficient under-drainage of agricultural lands, and even the increase of surfaced roads and pavements, lead to a higher run-off co-efficient in a river basin, so that, unless the bed of the river is artificially deepened, there is likely to be increased flooding or water-logging of low-lying lands. Again, where fen country is improved by dykes and canals, not only do the lowlands benefit, but the uplands, because of the general lowering of the water-table: hence the cost of drainage works can justly be spread over the whole river basin—whether they have been necessitated by improvements in the uplands, or because they effect such improvements: whether, however, the cost should be evenly apportioned is a more difficult matter to determine.

Multiple control of a river produces anomalies which are almost impossible to rectify when the river flows from one State into another. Thus, in the United States of America rivers cross State boundaries again and again, and although there is Federal control of navigable waterways, many such rivers are non-navigable. The Colorado River, for example, has been exploited near its mouth by the people of southern California, who have expended an enormous capital sum upon irrigation works, and upon building cities and providing transport facilities in the irrigated areas. The whole of the water which they utilize, however, has been collected by the river in other States, mainly in Montana and Colorado, and is delivered across the boundary of Arizona. The people of these up-river States have no concern with the prosperity of southern California, they already divert a part of the Colorado waters to their own irrigated areas, and it is possible that in the future so much may be diverted that in a year of exceptional low water there will be no delivery to California at all. On the other hand, irregular floods of great magnitude are characteristic of the Colorado, and an unusually high stage is equally a menace to the exceptionally low-lying irrigated valleys of southern California. The Californian community is, then, deeply concerned in the regularizing of the river up-stream by dams and barrages, yet has failed to secure the co-operation of the up-river States for this purpose.

Only in modern days has the multiple control of the Nile Basin become a matter of diplomatic importance. The gathering ground alike of the flood waters, and of the richly nutritive red silt is the kingdom of Abyssinia, while the laden waters must pass through the Anglo-Egyptian Sudan before reaching Egypt. Consequently the development of irrigation works in the Sudan is viewed by the Egyptians with grave uneasiness, although actually, in spite of the withdrawal of water up-stream, the volume available for the Egyptian fields is not diminished, provided that a sufficient head is maintained at the Assuan dam and at the barrages below it. The reduction is then in the volume of water that would otherwise run wastefully to the sea.

The further point arises, however, that when water is held up for a long period behind a dam it slowly changes from turbid to clear, as it does in a lake, owing to the settling down of the silt. The consequence is that while the water that runs freely through the sluices in flood time is fertilizing because silt-laden, that delivered to the permanently irrigated areas from the stored supplies is not. Hence the need for artificial manuring arises, making cultivation more expensive.

Where a river, as, for example, the Euphrates, carries a heavy load of coarse silt (the Nile silt is very fine), this load is rapidly deposited where there is any check on the current: consequently the erection of a barrage may choke the river, and to prevent this is a difficult engineering problem. The ancient Babylonians were faced continually with the task of keeping the irrigation canals from being closed up by silt, and when the land fell a prey to successive invaders, this task was neglected, and the marvellously fertile fields relapsed into their original semi-desert condition.

The problems arising from a lack of unified control present themselves in an acute form when a river has been selected as a whole or in part as an inter-state boundary. The Great Lakes and St. Lawrence system affords a case in point, for in part it is shared by Canada and the United States, although once the

St. Lawrence crosses the 45th parallel, it is entirely Canadian. The four upper lakes form a magnificent waterway, utilized mainly for the carriage of grain and ores; between the fourth lake and the fifth lake, however—that is to say, between Lakes Erie and Ontario—the Niagara Falls bar the natural waterway. Divergence of traffic at this point was inevitable, and, as it happens, the American city of Buffalo, above the Falls, stands where traffic would leave the lakes to pass eastwards, falls or no falls. Consequently American traffic routes, both by water and rail, meet the Great Lakes at Buffalo or further west, while to Canada has been left the task of circumventing Niagara by canal construction. The first small canal was superseded by a larger one, and this by a larger still, capable, in fact, of accommodating the largest ocean vessels afloat. Unfortunately, however, the section of the St. Lawrence between Lake Ontario and Montreal has a very steep gradient, and although the rapids are surmounted by locks and canals, these can only accommodate vessels drawing up to 12 feet. It is in this section, from the point of view of the waterway as a whole, that improvements should be effected. An International Commission has under consideration a scheme for this section that will provide, besides an ocean highway, hydro-electric power to the extent of 2,400,000 h.p., which must be shared on a 50 per cent. basis by the two countries concerned. Canada has, however, already a surplus of water-power, which is exported to the United States, while the great city of Montreal has grounds for fearing that should the scheme be carried out her prosperity would suffer, with loss of her position at the head of ocean navigation. Railway and shipping interests in the United States, too, have no reason to welcome the diversion of eastward-moving traffic to the all-Canadian St. Lawrence Estuary. Consequently the scheme has met with opposition from several quarters, although there is no doubt at all that in the long run it will give an impetus to the growth of industrial cities on both shores of the two lower lakes, and will benefit each nation as a whole.

Yet another anomaly of dual possession is illustrated by the Great Lakes and St. Lawrence system. During a past geological period the present outlet of the Great Lakes was blocked by ice, and their waters overflowed southward. Lake Michigan, for example, drained by the river Illinois and the Mississippi, the outlet stream passing the present site of Chicago. It was a very easy matter to reconstruct this vanished outlet, first as a drainage canal for the city sewage, and later as a navigation canal. To-day, therefore, a very large volume of water passes from Lake Michigan to the Mississippi, and the Harbour Board at Montreal has raised the point that this diversion may be responsible for the lowering of the water-level which has lately been apparent at the Canadian seaport. A connection between the two changes has not been proved, for detailed observations of the hydrography of the Lake and River Basin are wanting. Lake Michigan, besides, lies entirely in United States territory, and hence its waters are at the disposal of the United States.

The selection of a river as a frontier line has obvious advantages, for unlike a land boundary, it does not require demarcation, and passage to and fro across it is not difficult to control. Moreover, since a river is an economic asset, it is more equitable that its possession should be shared. Cases occur, however, where all these advantages are outweighed by the disadvantages attaching to a river boundary. Chief of these disadvantages is the liability of a river to change its course, as a river of irregular regimen may do in time of flood: parts of Mexico, for example, now lie on the American side of the Rio Grande, while the Colorado River no longer flows in the bed which it occupied when it was designated the boundary between the Mexican Provinces of Sonoran and Lower California.

A further case in point is afforded by the Red River, which runs between Texas and Oklahoma, and gave rise to a long and costly law-suit. The Red River is fed by the irregular yet torrential rains of the High Plains of the Far West, and carries an exceptionally heavy load of silt. In dry weather it is reduced to a network of narrow, braided channels, separated by great expanses of bare sand and gravel. At normal stage, the water fills the whole bed between the "cut banks," but after rain has fallen in the west, it floods the adjacent bottoms, and very heavy rains lead to the flooding of the second bottoms or "extraordinary flood-plain," separated by a low terrace from the first. In places, now on one side and now on the other, the bottoms, or flood-plains, are absent, and the river at mean stage washes directly the foot of the steep bluffs, which carry the level up to that of the great undulating plain across which the river flows.

Under normal circumstances, where a river is an inter-state boundary, the jurisdiction of the respective States extends to the median water line, and as and when the land is alienated, ownership of the river bed to the median line passes to the riparian landowners (save in the case of navigable rivers). Ownership of non-alienated land is vested in the Federal Government. In this particular case, however, Texas has inherited the old Spanish boundary line, which was not the median line, but the south bank of the river. Hence Oklahoma's jurisdiction of the surface of the river extends to the south bank, but Oklahoma riparian landowners only possess the bed as far as the median line, the part of the bed between that line and the south bank remaining Federal property. When the river is at low stage, therefore, a Texas farmer may find half a mile or more of Federal river bed between his fields and a drinking place for his cattle.

All this was, however, of little moment until the discovery that the Texas oilfield ran beneath the river bed, when the ownership of each square yard became a matter of concern. The dispute centred about the definition of the south bank, on which, of course, hinged the fixing of the median line. Arguments were advanced in favour of the foot of the bluffs, the edge of the first flood-plain, the normal cut banks, and the edge of the main channel at low stage. The decision was given that the cut banks served to define the boundary of Texas and the median line, but it could not be denied that, with such an unstable river, the position of the cut banks had altered during the eighty years or so since the boundary was first defined. According to United States law, where such a change is gradual, the boundary follows the changing line, but where there is a sudden change, and the river cuts quite a new channel, the boundary follows the old channel. In the absence of accurate maps of the river at the time of the original boundary treaty, it was impossible to establish any past changes, and so the present cut bank was accepted. It is clear, however, that owing to the instability of this line, a Texas oil-well may be transferred over night to Federal land, with an Oklahoma river flowing over it!

The great European rivers were "internationalized" by the Treaty of Versailles, and the policy pursued in respect of river development is decided by an International Commission, upon which one or more delegates from each of the riparian States have seats according to an agreed proportion. The conflict of interests remains, however, as is well illustrated by the case of the Rhine. This river has been trained and regularized up to the French port of Strasbourg (opposite which lies the German Kehl), so that this point is the head of navigation for large barges and river steamers. Above Strasbourg-Kehl the current is so swift (owing to the slope of the bed) and the river in places so shallow, that only small barges (up to 400 tons) can be tugged up to Basle and Rhinefelden in Switzerland. Now, the large industrial towns of French Alsace do not stand on or near the Rhine, so that from the French point of view it would be desirable to construct a canal-way (which would also provide power at the locks), which would take off at Basle, and passing through the industrial area, rejoin the Rhine at Strasbourg. For Swiss traffic, however, the scheme of deepening, training and regularizing the Rhine itself would provide the most economically efficient waterway: the passage through a canal with locks would necessarily be slow, and the tolls high, and Switzerland, a heavy importer of foodstuffs, fuel, and raw materials, is anxious for the removal of the severe handicap imposed by lack of cheap transport. The removal of water from the Rhine to fill the canal and provide the head for power would not only make the transformation of the upper Rhine into an effective waterway impossible, but might endanger the existing traffic facilities on the unregularized river.

In the case of the Danube, an International Commission has controlled the section used by ocean-going steamers, from Sulina to Braila and Galatz, ever since the Crimean War. Here the silting of the channel presents a problem very difficult of solution, for the navigation, even for vessels merely drawing up to 12 feet, is increasingly threatened. Above the delta, the riparian States are Rumania, Bulgaria, Yugoslavia, Hungary, Czechoslovakia, Austria, and Germany. Bulgaria and Yugoslavia have more direct outlets to the sea than the river provides, Rumania is sufficiently well served by Braila and Galatz, Hungary is deeply impoverished, as is Austria, while Germany is chiefly interested in routes to the west. Czechoslovakia, with a very active industrial and agricultural development, looks east for important markets and sources of grain and raw materials; hence at present this country has the greatest interest in the waterway. The indifference or incapacity of the other riparian States means lack of wharfage and docking facilities, restrictions on local traffic, delays at customs barriers, as well as unwillingness to effect any improvements in the channel of the river itself.

The completion of the new canal, with capacity for 1,000-ton barges, which will link the Rhine and Danube through the River Main, will increase the importance of the Danube, especially from a German and Austrian standpoint. The section of the river between these two countries is one of the difficult ones—the waters are confined in a gorge between Passau and Linz, so that they run very swiftly, and the confluence of the river Inn is just at Passau, with the result that an enormous volume of snow water is poured into the gorge in summer. The second critical section of the river is at the Iron Gate, where, in spite of heavy expenditure upon deepening the channel, the current is so swift at high stage as to make up-stream towage very costly. The third critical section, the delta, has already been mentioned, and it must be recalled that the whole river system is ice-bound for several months of the year, when all shipping must lie up.

France is fortunate in having complete control of the great river Rhone below Geneva, and a very comprehensive scheme for turning this river into an economic asset has been approved by the French Chamber. At present the Rhone is an extremely turbulent and dangerous river, but when the regularization is complete most far-reaching effects are expected. "First of all," writes Maurice Pardé in his recent monograph on the Rhone, "widespread irrigation will fertilize certain regions which have hitherto remained unproductive for lack of water. The Crau will become a garden and an orchard as rich in fruits, flowers, and early vegetables as the favoured regions of the lower Durance. Next, a magnificent waterway will be opened through a region marked out by Nature to be one of the greatest cross-routes of Europe. An enormous transit trade will enrich the whole of south-east France in consequence. The traffic of Marseilles will perhaps be immeasurably extended.

"Once the Rhone is regularized, a string of hydro-electric power generating stations will stretch from Geneva to the sea, yielding according to a moderate estimate, 700,000 h.p. for 355 days of the year, and 1,400,000 h.p. for six months; this represents a saving of millions of tons of coal annually. A part of this power will be carried to Paris, part will supply local needs, the rest will doubtless lead to a wonderful expansion of great and small industries in south-east France. Nor must the electrification of the P.L.M. railways be forgotten in this brilliant glimpse of the future!"

The peculiar and complex regimen of the Rhone, while making this grandiose scheme possible, will make it also very costly. The Swiss Rhone is naturally Alpine in character, but its summer flood waters lose themselves in the great reservoir of the Lake of Geneva. The lip of this deep lake is relatively shallow, and a barrage, constructed about forty years ago, maintains the head of water for the Geneva power-station. After leaving the Lake, the Rhone almost immediately receives the drainage of Mont Blanc and its margins, carried by the Arve, so that it rises to a very marked summer flood. Nearly eighteen miles below the Arve confluence the river enters the famous gorge of Fort l'Ecluse-Bellegarde, and here, during part of the way, the water disappears down a huge cleft, little more than two yards wide, but 200 feet deep. The solid cañon walls, and the small cross-section of the river gorge allow of the building of a gigantic barrage, which it is proposed to place at Génissiat, for the purpose of providing power—no navigation, of course, being possible.

Below the gorge, the Rhone receives the drainage of a large part of the Jura Mountains, by the River Ain, and as this river brings a maximum of water during the winter months, the seasonal fluctuations of the main stream are reduced. The steep slope of the bed is maintained to Lyon, where the impetuous torrent of the Rhone contrasts with the sluggish stream of the Saône which joins it at this point. Not far above Lyon, a huge electrical power-station on the Rhone, at Jonage, supplies the city and neighbourhood. The Saône has a regimen resembling that of the Seine—that is to say it is highest in winter, and is most likely to have exceptional floods in spring. It forms a strong contrast to the next great tributary, the Isère, which comes down from the Alps, and is markedly torrential in character, with summer floods due to snow melting. Yet another disturbing element is introduced into the regimen of the lower Rhone by the tributaries, such as the Ardèche, which join it from the Cevennes. The Cevenole rivers are subject to devastating floods in the autumn, due to the torrential downpours which mark the onset of the winter rainy season characteristic of the Mediterranean Basin. The fact that the rocks of the Cevennes are largely impermeable increases the suddenness of the rise of the rivers after a storm.

The navigation of the Rhone begins at Lyon, but again and again below that city the rock structure of the valley is such as to cause a constriction and steepening of the river bed, so that veritable rapids are formed. It is at these points that locks will be constructed, and the head of water made use of for power. In this, as in all river works, it will be necessary to allow a very large margin for vagaries of volume of flow. In the history of nearly every great river is the record of some appalling and disastrous flood, and probably every two centuries or so some combination of conditions is likely to occur which fills the river with a volume of water far beyond its capacity for disposal. The construction of artificial dams, barrages, and other obstructions intensifies the danger from such abnormal conditions, and the record of bursting dam catastrophes, such as the San Francisco dam near Los Angeles in 1928, is a warning of the wide margin that must be allowed for Nature's caprice.

CHAPTER V

THE OCEAN BASINS

THAT the earth's surface is divided into continents and oceans is often taken for granted as a fact needing no explanation, and reflecting merely the expected irregularity of the rock-built surface of a cooling planet. Actually, however, it is not a question of mutually related heights and hollows, grading imperceptibly the one into the other; a more or less sharply defined boundary, the continental slope, marks a sudden change from one type of distribution of crustal material —namely, in the form of continental blocks—to another type of distribution—namely, in the form of ocean basins. The fact that the ocean waters lap over the edge of the continental blocks in many places, forming shallow marginal seas, masks the true shapes of the continents and oceans. This drowned edge of the continents is termed the continental shelf, and there is abundant evidence that at certain geological periods there have been wide transgressions of ocean waters over the continental blocks, while other periods have been marked by complete regression of the waters to the edge of the continental slope. Such changes in the superficial extent of the land and water surfaces, important though they are in dictating climate changes, and influencing the distribution of life forms, are not to be confused with an actual change in the distribution of continental blocks and ocean basins. The theory of the permanence of the ocean basins is supported by many lines of evidence, and is in harmony with the view that the continents are composed of blocks of the lighter rock materials, collectively termed the sial, which are supported from beneath by the heavier materials, collectively termed the sima. The sima forms the floor of the ocean basins, and lies at a somewhat greater depth than this floor beneath the continents, since it is pressed down by the weight of the continental block of sial. Put in a somewhat extreme form, it may be said that the sial blocks float in the denser sima, like icebergs in water, and granted this premiss, it is possible that the forces generated by the earth's rotation may have caused an original single block of sial to split up and parts of it to drift equator-wards and westwards, as postulated by Wegener. The extraordinary configuration of the Pacific Ocean, bordered as it is on the east by a lofty Cordillera, and on the west by a sequence of islands and peninsulas arranged garland or festoon fashion, and stretching from Alaska to New Zealand, is then explained in general terms as the result of a westward drift of the Americas, ridging up mountain chains before them, and a westward drift of Asia, leaving the island loops dragging out behind it, caught in the enveloping sima. Such an explanation, however, is open to criticism, and even were it valid, the problem of the origin of continents and oceans remains unsolved, since there is no reason why the lighter sial should not have been uniformly distributed over the sima. The plausible hypothesis that the Pacific Ocean is the scar left by the birth of the moon is shown by Jeffreys to break down upon examination.

There is a certain rough symmetry about the arrangement of continents and oceans that has frequently attracted attention. The Arctic Ocean is matched by the Antarctic Continent; the almost complete ring of land round the Arctic Ocean is matched by the complete ring of ocean round the Antarctic Continent; three continental land masses taper southwards, and three oceans taper northward. If a model globe be turned about so that the French town of Nantes forms the centre-point to which the eye is directed, it will be found that the hemisphere in view is almost entirely a land hemisphere, while the opposite hemisphere is almost entirely water. Land and water are, in fact, roughly antipodal.

So long as it was considered that the continents were of the same material as the ocean floor, this dissymmetry of land masses represented an extra load in the land hemisphere, not easy to reconcile with the equilibrium of the globe as a whole. The difficulty disappears if it is assumed that the continental blocks displace their own weight of sima, and that the displaced sima is redistributed in such a way that everywhere an isostatic balance is maintained.

The difficulty of unequal distribution of mass about the centre of the earth was felt by the Greeks, and following the Greeks, by the Renaissance Geographers. The discoveries of the fifteenth and sixteenth centuries revealed the great extent of land in the Northern Hemisphere, and it was to balance this that great cosmographers like Mercator postulated a huge southern land mass, Terra Australis, which figured on sixteenth and seventeenth century world maps, and was only reduced to its correct proportions by the exploratory voyages of Captain Cook.

The details of the configuration of the floor of the ocean are only very imperfectly known, since it is less than a century ago that a means was found of taking a deep-sea sounding. The configuration of the continental shelf, on the other hand, is very accurately charted, for the practice of navigation by soundings in shallow waters goes back to classical antiquity. Nor has the method changed. The Greek sailor "heaved the lead," which was attached to a knotted line, and was greased with a lump of tallow, so that a specimen of the "bottom"—whether mud, shells, gravel, sand, or what not—was hauled up and added to the pilot's knowledge of his position.

The deeper waters were only removed from the category of the accepted unknowable when it became a matter of great practical importance that they should be known. The middle of the nineteenth century saw the laying of the first trans-oceanic cable, which ran from Valencia in Ireland to Trinity Bay in Newfoundland; after a few messages had been transmitted, the cable ceased to work, and elsewhere there was the same disappointing result. An impetus was therefore given to deep-sea exploration which should throw light on the cable problem. One step forward was the invention of a practical deep-sea sounding apparatus by a young American midshipman named Brooke. This consisted of a cannon ball pierced by a hole, through which ran easily a hollow rod, serving as a sounding-tube. The cannon ball was attached to the sounding-line by a wire sling, which became detached from the line immediately the weight of the ball was supported from beneath, as would occur when the apparatus touched bottom. Thus the sounding-tube was carried down by the weight of the cannon ball, and was drawn up relieved of that weight. The inside of the hollow tube was greased, and it brought up a specimen of bottom material.

The use of Brooke's sounding apparatus brought into the scientific laboratories specimens of the floor of the ocean deeps hitherto quite unknown. The result was to throw doubt on the accepted theory that there was no life at great depths, and the controversy thereby initiated among biologists gave a further stimulus to oceanic research. At a somewhat earlier date the new "Wind and Current Charts" of Lieutenant Maury, of the United States Navy, had proved extraordinarily valuable to ship-masters, and had led to considerable shortening of the time of sailing voyages. Consequently there was a general consensus of opinion in favour of systematic exploration of the oceans from every possible aspect. A practical outcome of this situation was the fitting out of the famous *Challenger* Expedition. The *Challenger,* lent by the British Admiralty, was a fully equipped and manned corvette of 2,306 tons, fitted with auxiliary steam. The voyage of circumnavigation carried out, and the special study of the Atlantic Ocean, lasted over three years (1873-76), while the data collected provided material for the leading oceanographical charts of the next thirty years.

The process of taking a depth sounding on the *Challenger* lasted several hours, and it was necessary for the vessel to be hove to while the stout hempen cable was paid out and slowly drawn in again. The modern Lucas deep-sea sounding machine is fitted with several miles of steel piano wire, wound on a drum, and the length paid out until the sinker is detached is automatically recorded. Directly the sinker touches bottom, a brake is released which checks the unwinding. The time taken is very much less than with the hempen cable, but it is still necessary to stop the ship.

Soundings, can, however, be taken continuously by a ship that is under way by means of the lately perfected Echo sounding apparatus. An electrically controlled and timed explosion, made on the ship's bottom, sends out a sound-wave which is reflected from the sea floor; the moment of receiving the echo is automatically recorded, and the velocity of sound being known, the depth to the sea floor can be calculated. Actually the apparatus is so constructed that the depth is read directly from the scale, but correction must be made for variations of temperature and salinity, which affect the velocity of the sound-waves. This apparatus was successfully used by the German *Meteor* Expedition, which made a study of fourteen cross-profiles of the South Atlantic during the years 1925-27.

The Echo sounding apparatus merely records depth, and cannot replace the Lucas sounding machine if a specimen of the bottom deposit is also required. The

Lucas apparatus is fitted with a set of four tubes, closed by spring valves, but this may be replaced by a grab, the open jaws of which automatically close when the sinker touches bottom. The deposits of the sea floor have been charted on general lines, and the results are of the greatest interest. Broadly speaking, such a chart shows that the continental shelf and continental slope are floored with the waste of the continents, the so-called Terrigenous Deposits, while the ocean basins are floored with oozes, which consist largely of the remains of minute marine organisms. These deep-sea oozes are termed Pelagic Deposits, to emphasize the absence of any connection with the land. Since it sometimes happens that the fauna and flora of relatively shallow waters is so abundant as to cause organic remains to predominate over the inorganic waste of the lands, a third category of deposits, the Neritic Group, is required.

The Terrigenous Deposits may be sub-divided into zones according to the depth of the water. The term "littoral" is applied to the deposits between tide marks, which consist of material immediately derived from the adjacent land, and varying, therefore, according to the character of that land. Huge boulders of rock, wave-worn flints, pebbles of all descriptions, shingle, sand, and mud, are all familiar beach materials. These may be mingled with foreshore Neritic Deposits, including shells of bivalves and the sandy tubes of marine worms. The term "shallow water deposits" is used for the terrigenous and neritic deposits found on the continental shelf but not exposed at low tide. Here boulders and large stones or pebbles are absent, for only the smaller and more completely worn down fragments of rock waste are carried so far from the shore. Sands are most characteristic, but these may be replaced by muds, or may be mingled with shell and coral fragments.

Coral reefs and the fragments of coral reefs form the most striking of the Neritic Deposits, although they occur only in localities suitable to the coral building organisms. Where the coral reef occurs on a continental margin, the coral waste will be mingled with the terrigenous deposits of the littoral and shallow water belt, but round oceanic islands, where there is very little terrigenous waste, almost pure coral sands may occur. The Neritic Deposits round oceanic islands may be termed Oceanic Neritic Deposits, to emphasize the absence of any admixture of continental detritus.

The strong tidal currents and eddies, and the violent wave motion, that are characteristic of the continental shelf, cause the very fine particles of continental waste to remain in suspension in the agitated water. Beyond the edge of the shelf, however, the waters, save near the surface, are perfectly still, and the very finest particles here settle down upon the floor. Hence, the continental slope is covered with extremely fine mud of terrigenous origin. These marginal muds are subdivided according to colour. The predominant deposit is the Blue Mud, which is actually blue-black; there are also the Green Muds, containing particles of the green mineral glauconite, while the Red Muds are tinged by iron oxide.

The deep-sea oozes, or Pelagic Deposits, are subdivided according to the pelagic organism most prominent in their composition. The Pteropod Ooze, for example, is characterized by entire and broken shells of the small, drifting molluscs called pteropods and heteropods. This ooze occurs in relatively small patches on rises in the ocean floor, where the depth of water is between 400 and 1,500 fathoms. The most widely spread ooze is that called Globigerina, which covers the greater part of the floor of the Atlantic Ocean. It is highly calcareous, and contains the remains of numerous pelagic foraminifera, especially those belonging to the genus globigerina, from which it takes its name. This ooze occurs, as a rule, at depths between

1,200 and 2,200 fathoms, although it may be found at as great depths as 3,500 fathoms.

Globigerina Ooze passes over into Red Clay as the depth of the ocean increases, and in the Pacific Ocean red clay is the most characteristic deposit. Sir Wyville Thomson writes of its first discovery by the *Challenger* observers as follows: "The small dredge was sent down at 2.15 p.m. . . . 3,600 fathoms of rope were paid out, 1,000 fathoms 2 inches in circumference, and the remainder 2½ inches. The dredge came up at 10.15 p.m. with about 1 cwt. of red clay. This haul interested us greatly. It was the deepest by several hundred fathoms that had yet been taken, and, at all events, coincidently with this great increase in depth, the material of the bottom was totally different from what we had been in the habit of meeting in the depths of the Atlantic. For a few soundings past, the ooze had been assuming a darker tint, and showed on analysis a continually lessening amount of calcareous matter, and, under the microscope, a smaller number of foraminifera. Now, calcareous shells of foraminifera were entirely wanting, and the only organisms which could be detected after washing over and sifting the whole of the mud with the greatest care were three or four tests of foraminifera of the cristellarian series, made up apparently of particles of the same red mud. The shells and spines of surface animals were almost entirely wanting; and this is the more remarkable as the clay mud was excessively fine, remaining for days suspended in the water, looking in colour and consistence exactly like chocolate, indicating therefore an almost total absence of movement in the water of the sea where it is being deposited. When it at length settles, it forms a perfectly smooth, red-brown paste, without the least feeling of grittiness between the fingers, as if it had been levigated with extreme care for a process in some refined art. On analysis it is almost pure clay, a silicate of alumina, and the sesquioxide of iron with a small quantity of manganese."

It is considered that this inorganic deposit, the red clay, found far from the land, must consist of an age-long accumulation of wind-borne dust, of volcanic dust gradually settling out of the atmosphere, and of meteoric dust from inter-stellar space. Organic remains, filtering slowly down from the surface zones of the water, would be dissolved before reaching such great depths, although certain practically insoluble organic fragments, such as sharks' teeth, and the ear-bones of whales, are, in fact, found in the clay. It must be emphasized that owing to the time and expense involved in making even a single observation, the available data for studying the sea-floor deposits are still relatively scanty. The German *Meteor* Expedition, for example, took complete observations at 360 stations only during fourteen traverses of the South Atlantic from side to side. These, however, may be expected to yield very interesting results, and, in particular, data have been obtained as to the super-position of different types of bottom deposit, and it is probable that bottom currents are more frequent and play a greater part in determining the distribution of deposits than has hitherto been supposed.

What may be regarded as a local variety of Red Clay—namely, Radiolarian Ooze—is found over limited areas in the deeper parts of the Pacific and Indian Oceans (below 2,000 fathoms). The special characteristic of this ooze is the presence in varying proportions of the siliceous remains of the minute organisms called Radiolarians.

One further variety of pelagic deposit requires notice, namely, the Diatom Ooze. It contains the siliceous parts of minute unicellular plants called diatoms, and is found in a broad band round the Antarctic Continent, outside the Mud Belt. It also borders the Pacific Ocean to the north, but is absent in the Atlantic, Arctic, and Indian Oceans. Marine organisms are extremely sensitive to small variations in the salinity and temperature of sea water, and the distribution of diatoms in sufficient numbers to form diatom ooze may be bound up with the occurrence of a certain combination of physical characters in the ocean waters.

CHAPTER VI

THE OCEAN WATERS: TEMPERATURE AND SALINITY

IT was very early observed that sea water is not everywhere equally salt, and especially that it was fresher in the neighbourhood of great river mouths, and of melting icebergs. Elizabethan writers, indeed, found in such variations of salinity what they deemed to be cogent arguments for and against the existence of the North-East and North-West Passages. Inequalities of temperature are less obvious to the observer unequipped with instruments, but in 1775 Dr. Franklin discovered the sharpness of the thermal boundary of the Gulf Stream, and devised instructions and charts whereby a ship's captain could ascertain his position by dipping a bucket over the side and testing its contents with a thermometer. Such a determination, crude though it must have been, was valuable at a date when the chronometer had not been perfected, and the problem of a rapid observation of longitude remained unsolved.

As in the case of deep-sea soundings, the problem of making deep-sea observations of temperature and salinity presented considerable difficulties. The *Challenger* observations of temperature were obtained by means of maximum and minimum thermometers, attached at definite intervals to the sounding-line, and the reading obtained was of the minimum temperature between the surface and the fixed depth, which was not necessarily the temperature at that depth. The modern instrument employed is a reversing thermometer, so constructed that the temperature reading at the instant of reversal is recorded when the instrument is inspected. The reversal is effected at the desired depth by means of a messenger sent down the line.

Specimens of water for salinity determination can be obtained by sending collecting bottles down to any specified depth. These bottles are provided with upward opening valves, which allow free passage to the water during descent, and can be hermetically sealed by a screw propeller set in motion when ascent begins. A triply insulated collecting bottle is sometimes employed, into which a thermometer is inserted. The unaltered temperature of the contained water is then read off directly from the protruding stem of the thermometer and the specimen set aside for analysis.

The actual determination of salinity depends upon the fact already noticed that whatever the percentage of salinity may be, the relative proportion of the contained salts is constant. Hence it suffices to make a chloride determination, when, by application of an empirically determined formula, the total salinity can be calculated. The chloride is brought down as an insoluble precipitate by means of a silver nitrate solution, and the strength of the nitrate solution being determined by titration against standard sea water, the amount of chloride present can be found. The density of sea water is a function of its temperature and salinity, so that if these two latter values are determined, the density can be calculated from the tables. The usual direct methods can be employed, but they must be carried out with great refinement, since the variations of density are very slight, though of considerable significance.

Whatever physical characteristic of sea water is measured, the result shows that two very different bodies of water can be recognized in the oceans—namely, the surface waters and the deep waters. The former are penetrated by light, heated and evaporated by the sun's rays, diluted by rain, set in motion by the winds, and in general subjected to direct external influences; the latter are remote from such influences, and so are less subject to periodic and aperiodic changes. As will be seen later, however, the deep waters are by no means stagnant, but take their part in a constant circulation which insures their renewal.

The temperature distribution in the surface waters is a matter of great importance, since it influences the temperature of the air passing over the water, and hence indirectly influences the climate of neighbouring land areas. The well-known contrast between the winter temperatures of the British Isles and Labrador respectively, two countries lying within the same latitudes, is due very largely to the presence of warm surface waters off the former, and cold surface waters off the latter land area. These contrasting surface waters result from the general oceanic circulation, which will be dealt with later, but it should be noticed that the contrast would be far less marked were it not for the land-ice from Greenland which enters the Labrador Current in the form of icebergs, and lowers its temperature very considerably. The gigantic tabular icebergs of the Antarctic also determine anomalous temperatures in the surface waters moving out from the Southern Ocean, and should the ice-caps of Greenland and Antarctica completely disappear, the function of the sea as a regulator of heat would be more completely fulfilled.

The average surface temperature of the sea, during the hottest time of the year, does not rise, even in the tropics, above 27° or 28° C., except in enclosed seas where the conditions are anomalous. More important, however, is the fact that, although a land surface may fall 50° or 60° below freezing, the lowest temperature recorded for a water surface is 3·3° C. This is due to the fact that at two or three degrees below zero field-ice forms, which preserves the waters beneath from further loss of heat. The contrast between the surface water temperatures in summer and winter respectively is under 5° within the tropics, and from 5° to 10° in extratropical regions, where the seasonal contrasts of insolation are greatest. In the few localities where more marked temperature ranges are found, the explanation lies in the alternation of warm and cold currents, due to seasonal changes in the winds.

The surface distribution of salinity is largely a function of evaporation. Maximum salinities are found in the Horse Latitudes and trade wind belts, where the values rise to 37·5 parts of salt per thousand, while minimum salinities, under 34 per mille, are found in high latitudes. The effect of the discharge of river water is seen in the lowering of salinity towards the continental margins, and the effect of current circulation is shown in anomalies of salinity for the same latitude. The passage of land-ice into the ocean, since it contributes a large volume of fresh water, accentuates the salinity anomalies as it accentuates the temperature anomalies, and hence, as will be seen later, is a powerful factor in determining the general oceanic circulation.

The salinities of enclosed seas vary very widely. The cold Baltic Sea, abundantly fed by rain and rivers, has a salinity of 5 to 8 per mille only, while the warm Eastern Mediterranean has a salinity of over 39 per mille, and the Red Sea of over 40 per mille.

The vertical distribution of temperature, from the surface of the ocean floor, has certain features in common throughout the oceans: there is a very rapid fall of temperature through the first 200 fathoms, when the rate of change becomes more gradual, falling steadily until about 1,200 fathoms is reached, after which any further changes are very slight indeed. The following figures, observed from the *Challenger* on the voyage between the Canaries and the West Indies are typical:

Station I.		Station II.		Station III.	
Depth. Fathoms.	Temper. °C.	Depth. Fathoms.	Temper. °C.	Depth. Fathoms.	Temper. °C.
Surface.	22·5	Surface.	24·0	Surface.	20·0
100	19·4	100	20·0	100	17·0
200	14·9	200	15·6	200	13·9
300	11·9	300	9 7	300	11·2
400	8·5	400	7·0	400	9·4
500	5·9	500	5·3	500	7·7
600	5·0	600	5·0	600	6·8
700	4·6	700	4·6	700	6·0
800	4·3	800	4·0	800	5·2
900	4·0	900	3·5	900	4·7
1,000	3·3	1,000	3·3	1,000	4·0
1,100	3·2	1,100	2·7	1,100	3·5
1,200	2·9	1,200	2·7	1,200	3·0
1,300	2·7	1,300	2·8	1,300	2 5
1,400	2·5	1,400	2·7	1,400	2·7
1,500	2·6	1,500	2·5	1,500	2·0
2,325 (bottom)	1 7	2,975 (bottom)	1·6	2,740 (bottom)	2·0

Anomalies of vertical temperature distribution are introduced by vertical movements of the water, as, for example, when dense saline water sinks from the surface, carrying with it its high surface temperature; or conversely when for any cause there is an upwelling of deep-seated waters, which bring an unusually low temperature to the surface. Horizontal sub-surface currents, too, may often be detected by the irregularities they introduce into the vertical temperature gradient. A warm layer of water may penetrate between colder layers, or *vice versa,* with the result that there is an inversion of temperature such as may occur in the atmosphere, where the temperature normally falls with increasing altitude. The possibility of a warmer layer of water underlying a colder is a consequence of the fact that density is a function of salinity as well as of temperature : a very warm body of relatively salt water may be heavier than a cooler body of relatively fresh water. It may be emphasized that moving bodies of water tend to preserve their individuality, as indicated by temperature and salinity, unchanged for very long periods, and mingling with neighbouring bodies of water does not readily take place.

Seasonal contrasts of temperature distribution have disappeared at 200 fathoms, and at this depth the differences of temperature according to latitude are much less than at the surface. The highest temperatures are from 16° to 17° C., met with in the area beneath the Sargasso Sea of the North Atlantic Ocean. In the South Atlantic, Pacific, and South Indian Oceans the highest temperatures are from 12° to 14°, and occur in positions corresponding to that of the Sargasso Sea—*i.e.*, towards the west of the Ocean basin in question and between latitudes 20° and 30°. In equatorial latitudes the temperatures at 200 fathoms are round about 8°, and in polar latitudes a little above zero.

The bottom waters of the oceans are surprisingly uniform in temperature, whether they lie beneath the equator, the tropic, or the pole. Generally speaking, they have a temperature of from 1° to 2° above zero, but in the North Atlantic Ocean the bottom temperatures are a little higher—*i.e.*, from 2° to 4°. The explanation is to be sought in the circulation of the waters : the Norway Sea has a bottom temperature which may fall below zero, but it is cut off from the rest of the Atlantic by the Wyville-Thomson ridge, which runs from Scotland to Iceland, and consequently its cold bottom waters are prevented from entering the Atlantic. In the South Atlantic Ocean the eastern basin is partly protected in the same way by submarine ridges, so that its bottom waters are a little warmer than those of the western basin. Just on the equator, however, there is a cleft in the bounding ridge, which here runs from east to west, and the researches of the *Meteor* Expedition reveal that a stream of the colder water makes its way through this cleft.

Anomalies of temperature with depth are very characteristic of marginal and partially enclosed seas, owing to their immunity from the invasion of cold bottom waters. The Mediterranean Sea, for example, receives an influx of surface Atlantic water to make up for the great evaporation during the summer months; the temperature of this entering water is, however, never less than about 12° C., and the whole of the Mediterranean Basin is filled with water at temperatures of from 12° upwards. The consequence is that there is a difference of many degrees between water at the same depth inside and outside the submarine ridge across the Strait of Gibraltar.

The more striking contrasts of salinity are a surface feature only, and are greatly reduced in the deeper waters. The tendency of the quiet, very hot, and saline surface waters of areas of the type of the Sargasso Sea to sink under gravity explains why the maximum of salinity for 200 fathoms is found beneath such areas, just as is the maximum of temperature at the same depth. The bottom waters have a uniform salinity of from 34·5 to 34·9 per mille. Partially enclosed seas are again anomalous as regards the distribution of salinity with depth. In the Mediterranean Sea for example, the deeper waters have a salinity of 38 per mille as compared to that of 36 per mille for the waters at the same depth outside the Strait.

Sea water is slightly alkaline in its reaction, and this alkalinity increases its power of dissolving carbonic acid gas from the atmosphere. In the upper waters the activity of organic life may remove this carbon dioxide very rapidly, the carbon being fixed as carbohydrate by the processes of assimilation and the oxygen being set free. Besides oxygen obtained by this means, the sea contains oxygen dissolved directly from the atmosphere, and it is of interest to notice that the proportion of dissolved oxygen to dissolved nitrogen in sea water is very nearly as 1 to 2, whereas atmospheric air contains the two gases mixed in the proportion of 1 to 4. Typical curves relating oxygen content to depth, as obtained by the *Meteor* Expedition, show that the volume of dissolved oxygen per unit volume of water passes from a maximum at the surface to a minimum at about 100 to 200 fathoms; it then increases again until a depth of about 2,000 fathoms is reached, after which it remains constant with further increasing depths, but is slightly reduced in the layer of water immediately in contact with the ocean floor.

The presence of as much, or sometimes even more, dissolved oxygen in the very deep waters as is found at the surface is due to the fact that these waters are constantly renewed by very slow currents derived from the surface at some far distant point. The layers most deficient in oxygen are those in which marine life is most active, the oxygen being breathed by fishes and other animal organisms. Under exceptional circumstances bodies of absolutely stagnant water occur, notably in the depths of the Black Sea, and in certain Norwegian fiords. In such cases there is no renewal of oxygen, and as the original content has long been removed, no organic life is possible. In the Black Sea sulphuretted hydrogen is present.

The proportion of gases and salts in solution in sea water is of the greatest importance in relation to fish life. It has been shown, for example, that the invasion of the continental shelf of western Europe by an unusual volume of water having a temperature and salinity above the normal is disastrous to the herring fishery. Fishes are, indeed, sensitive to changes in the water of so slight a character that the ordinary methods of observation fail to detect them. It has recently been found, however, that the degree of dissociation of the water, as measured by the concentration of hydrogen ions, can be determined with great refinement. The hydrogen-ion concentration, symbolized by PH., varies with the temperature, salinity, carbonic acid content, alkalinity, depth, distance from land, activity of carbon assimilation, and so forth. It consequently serves as a sensitive index in the study of sea water from a biological standpoint.

CHAPTER VII

THE OCEAN WATERS: WAVES, TIDES, AND CURRENTS

The waves of the sea, although the most obvious of its motions, are quite superficial, affecting merely the surface layers to a maximum depth of 100 fathoms: they are chiefly important for their destructive powers, and especially for the part they play, after they have "broken," in the actual shaping of the coast line. It is a matter of common observation that ordinary waves are due to the agitation of the sea by the wind, but any mechanical disturbance of a body of water will set up a rhythmic or wave motion and the large scale oscillations miscalled "tidal" waves are due to crustal displacements, either in the form of earthquakes or volcanic outbreaks.

The true tides are due to the combined effect of the tide-generating forces of the moon and sun, which reinforce or partly neutralize one another according to the relative positions of the three heavenly bodies concerned; the most favourable and unfavourable combinations are familiar as the fortnightly spring and neap tides. The tide-raising force is at a maximum at the point immediately opposite the attracting body, and at the point exactly antipodal to this—*i.e.*, when the moon is in the zenith and at the nadir, and the diurnal rotation of the earth results in a semi-diurnal periodicity of the tide. The tide-raising force is a minimum when the attracting body is on the horizon. Since the plane of the moon's orbit is inclined to the equatorial plane of the earth, and the latter is inclined to the plane of the earth's orbit, the moon, like the sun, has a varying declination, with the result that the direct and antipodal tide-raising forces differ for a particular latitude except when the declination is zero. Thus, if the moon's declination is 10° N., the maximum tide directly beneath the moon will be experienced once in the twenty-four hours at every point on latitude 10° N. The moon is in the nadir, however, in 10° S., where the antipodal tide will be at its maximum. Hence there is a diurnal periodicity in the tides, which may be expressed by saying that a high high tide is followed rather more than twelve hours later by a low high tide; the contrast will be greatest when the moon's declination is a maximum, which occurs twice a month, while a similar contrast in the tides produced by the sun in a particular latitude will be a maximum only twice a year. At the time when the moon's greatest declination most nearly coincides with the sun's greatest declination, equinoctial spring tides will occur. Further periodicities are introduced by the fact that the moon's orbit and the earth's orbit are alike elliptical. The moon's tide-raising force is a maximum when she is in perigee (once a month), and the sun's tide-raising force is a maximum when he is in perihelion (once a year). Certain very favourable conjunctions of maximum tide-raising forces occur at very long intervals (many centuries), and it is possible that these extraordinary tides account for catastrophic inbreaks of the sea. Such a tide may chance to be reinforced by a strong wind, which drives the water bodily before it, and the sea-level may also be lowered in one place and raised in another by a sustained difference of atmospheric pressure. The removal of the force maintaining the sea at an abnormal level may result in a movement of oscillation about the position of equilibrium, and tide gauges record such oscillations (varying in period according to the dimensions of the body of water concerned) superimposed upon the tidal movements.

The diurnal period of the tides is not well marked in the North Atlantic, so that two fairly equal tides a day are the normal phenomenon; in other parts of the world, however, the contrast between the high high tide and the low high tide may be so great that to the ordinary observer the tide comes in only once a day. This is the case on the Pacific coast of North America.

It is possible that the tides can be more satisfactorily explained in terms of stationary waves—*i.e.*, oscillations of the water about one or more nodes, than as progressive waves travelling round the globe under the impulse of the tide-raising force. In the case of certain lakes—*e.g.*, the Lake of Geneva—the to and fro oscillation of the water, leading to a rhythmic rise and fall of level, is a well-known phenomenon, and is termed a *seiche:* in such a case the disturbing force is the distribution of atmospheric pressure. The famous high tide in the Bay of Fundy, with a range up to 50 feet, appears to be an oscillation of the water in the trough-like bay, and not an advancing wave. In the case of a larger body of water, such as the North Sea, the effect of the earth's rotation is to transform the simple to and fro tidal oscillation into an oscillatory movement travelling in a counter-clockwise direction about a neutral point termed the amphidromic point. Such a movement explains the occurrence of high tide at later and later hours from north to south along the British coast, and from south to north along the European coast, as satisfactorily as the theory of a travelling tidal wave.

Although the major initial disturbance of the equilibrium of the ocean waters is the moon, the actual time of high tide at a particular place does not coincide with the passage of the moon across the meridian. The wave crest, whether oscillatory or progressive, travels from point to point with its own velocity, and is locally transformed into an actual ebb and flow of water controlled by surface configuration, especially in estuaries. Hence some time elapses between the moon's transit and the hour of high water, and the average value of this time interval is termed the "establishment of the port." The ability to predict the hours of high and low water is of such importance to pilots that an empirical knowledge of the establishment was arrived at in very early times. Data concerning certain European ports appear on the famous Catalan Atlas made for Charles V. in 1375, but a knowledge of the facts goes back much further than this. To-day the Admiralty publishes detailed Tide Tables, based on accurate observation, which allow the exact prediction of the state of the tide at any hour on any date for all important ports. As has already been stated, however, exceptional pressure and wind conditions may on rare occasions falsify such predictions, and the tide may apparently fail to rise, or may exceed its predicted range.

The possibility of utilizing the energy of the tides for the generation of power has often been discussed, and there are, of course, old tide-mills which are turned directly by the ebbing and flowing tidal current instead of by a river. Such a direct use of the movement of the water, however, gives very feeble results. Other devices are the use of a float, geared to machinery, which rises and falls vertically in a chamber to which the tide has access, and the compression of air in a closed chamber entered by the tide, work being done by the air on re-expanding. Both these methods give very small horse-power, and there is the further point that at slack water no power is available. The most promising method of utilization of the tides is by the so-called Basin System. A high-level basin is filled at every high tide, and maintains a constant head of water which drives a turbine engine: in this case the power available varies as the area of the basin and the square of the tidal range. It must be noted, however, that ranges up to 30 feet, which are common round the British Isles, and on the French side of the Channel, are exceptional over the greater part of the world. In the United States, for example, no port has a tidal range exceeding 10 feet, and the cumbersome devices of closed docks or floating docks are unnecessary. Owing to the fact that the Mediterranean Sea is practically tideless, the British tides appeared a remarkable phenomenon to the Greeks and Romans, and they formed a subject of comment by Pytheas of Massilia, the first educated Greek to visit Britain (*circ.* 330 B.C.). The Venerable Bede, too, writing in the eighth century, remarks on the double tide in the Solent, while the Anglo-Saxon Chronicle tells of a catastrophic tide in 1014: "This year, on the eve of St. Michael's day, came the great sea-flood, which spread wide over this land, and ran so far up as it never did before, overwhelming many towns, and an innumerable multitude of people."

The ocean currents proper (having no relation to tidal currents) are perhaps the most interesting, as they are the most intricate, of the movements of the ocean. They have far-reaching effects in determining the distribution and abundance of marine life, and attention has already been drawn to the part they play in determining anomalies of climate. Their aperiodic variability is the result of irregular variations of the weather, and in its turn produces further weather changes: as the chain of cause and effect works itself out but slowly, a study of ocean currents may be a valuable aid to the long distance forecasting of weather.

The problem of the causation of ocean currents has been very keenly debated. The great voyages of exploration of the fifteenth and sixteenth centuries revealed the existence of a strong westward movement round the south-east of Africa and across the tropical belt of the Atlantic Ocean. It was, therefore, surmised that the ocean waters as a whole moved westward, under the influence of that *primum mobile* which carried sun, moon, and stars westward across the sky.

By the time that the motion of the earth had been accepted, the discovery of the eastward moving Gulf Stream had made a fresh explanation necessary. "What is the cause of the Gulf Stream," writes Lieut. Maury, "has always puzzled philosophers." He himself inclined to the view, supported by modern research, that the constant circulation of the sea was maintained by the constant differences of specific gravity due to contrasts of temperature and salinity. A popular view was that the Gulf Stream represented the outflow from the Gulf of Mexico of the waters of the Mississippi. Dr. Franklin held that the famous stream was due to the escape through the Straits of Florida of water forced into the Caribbean Sea by the strong, steady trade winds, blowing from the east; while Sir John Herschel wrote: "The dynamics of the Gulf Stream have of late . . . been made the subject of much (we cannot but think misplaced) wonder, as if there could be any possible ground for doubting that it owes its origin *entirely* to the trade winds."

Actually, the same temperature contrasts between the equator and the poles that set up the planetary circulation of the atmosphere must set up a similar circulation in the ocean waters, which the air movements reinforce. Just as the distribution of land and water introduces complexity into the wind system, so, and to a much more marked degree, the opposition of the land masses introduces anomalies in the current circulation. In the case of the Gulf Stream, the canalization of the issuing body of water in the narrow Straits of Florida gives the current its exceptional velocity and depth: it has a maximum velocity of 5 knots, a maximum depth of 60 fathoms.

A current, with a velocity of from 0·5 to 5 knots, may be distinguished from a drift with a velocity not exceeding 12 miles a day, and a drift may be distinguished from a creep, which moves so slowly that it can only be detected by the physical characteristics of its water, which prove it to have originated elsewhere.

Flotsam and jetsam of alien origin throw light on the surface circulation of the oceans: a fragment of cane from the West Indies may reach the shores of Scandinavia, or a log from Siberia serve as the roof-tree of an Eskimo hut in Greenland. Such casual evidence of the direction of currents and drifts has long been supplemented by the simple device of casting bottles into the sea, directions being enclosed so that the finder may notify the experimenter as to the place where the bottle is cast up. Many such bottles however, are never found or reported, while although they give information as to the destination of a drift, they tell little as to its course thither. Drifting wrecks, the position of which is noted by passing ships, are valuable sources of information, as are floating icebergs. It is found, however, that if a considerable surface of the floating body emerges above the water, the drift may be controlled by the wind rather than by the current.

A ship's captain makes an indirect determination of the velocity and direction of the currents that he encounters, since the difference between the ship's position as determined by dead reckoning and that determined by astronomical observation represents its drift on account of the current. This rough-and-ready method, although it has served to provide material for general current charts, must be superseded by direct observation for scientific purposes. A current meter has therefore been devised which records both the direction and velocity of the movement, and which can be used at any depth.

In order that the apparatus may set itself in the direction of the current, it has a large vane attached, which causes it to swing round into the current. Since, however, the current direction varies with depth, a self-recording device is necessary. In the

Ekman current meter, a heavy magnetic needle is poised above a box containing thirty-two compartments. The needle maintains a constant direction, while the box twists beneath it with the rest of the apparatus. At regular intervals a small metal ball is released by a clockwork mechanism, so that it rolls on to the magnetic needle, and falls through a slot into the compartment immediately beneath. By examining the distribution of shot in the boxes, the mean position of the apparatus relative to the magnetic north is obtained. The velocity of the current is measured by means of a light propeller, which revolves at a velocity proportional to that of the current, and of which the rate of revolution is automatically recorded. Thus the complete data required are determined.

Ekman's studies of currents at different depths confirm interesting differences, determined by mathematical analysis, between those movements due to the wind and those due to differences of density. A wind-propelled surface current will be deviated owing to the earth's rotation, in accordance with Ferrel's Law : this deviated motion will be transferred by friction to the next underlying layer, although with diminished velocity. The direction of movement of this under-layer will in its turn undergo deviation owing to the earth's rotation, and this new direction will be impressed on a layer at a still greater depth. The process will continue, the direction of movement undergoing an ever-increasing deviation from the original wind direction, while the velocity of movement will rapidly diminish. In the case of a column of water set in motion by a difference of density, the motive force is no longer confined to the surface, but acts throughout the column. The deviation due to the earth's rotation diminishes, however, with depth, owing to the frictional resistance developed by the great pressure far below the surface.

The circulation of the South Atlantic Ocean affords a characteristic illustration of a current system. The general surface movement between the equator and lat. 20° S. is from east to west, at an angle of about 45° with the south-east trade wind. The blunt shoulder of Brazil acts as a wedge dividing these waters into two: a very strong stream flowing north-westwards crosses the equator, while a second stream is directed south-westwards, and, as the Brazil Current, can be traced as far as the Plate Estuary. Here it encounters the Falkland Current, the waters of which are cold, bottle-green (the Brazil Current is deep blue) and rich in organic life. In the belt between 35° S. and 45° S. the warmer water from the tropics flows over the colder water from the Southern Ocean, and the general movement changes to the east, assisted by the prevailing westerly winds. Drifting ice from the Antarctic reaches lat. 40° S. before completely melting, and so reduces the temperature of the easterly drift. When the ocean is crossed, the strong Agulhas Current, flowing round the south of Africa, acts as a barrier and diverts a part of the drift northwards along the African coast, where it is known as the Benguella Current. The low temperature of this current contributes to the dry conditions which prevail along the immediate coast of West Africa very nearly to the equator, and there is a difference of over 5° C. between the surface temperatures in the west and east of the South Atlantic in the same latitudes. Northward of lat. 30° S., there is an increasing tendency for the surface water of the Benguella Current to be drifted eastward, under the influence alike of the wind, and of the earth's rotation, and once lat. 20° S. is reached the general movement is eastwards, as already described. The general circulation is, therefore, in a counter-clockwise direction round an area devoid of currents which lies in the centre of the ocean basin, but displaced somewhat to the west. This area corresponds to the Sargasso Sea of the North Atlantic, and is a region of high salinity due to great evaporation. The tendency for water to be drifted away from the African coasts causes an upwelling there of the deep-seated waters, which maintains the low surface temperature. Off the Brazil coast, on the other hand, the waters to considerable depths are abnormally warm and salt.

The sub-surface circulation of the South Atlantic has been investigated by the recent German *Meteor* Expedition, which, as already stated, obtained data along fourteen cross-profiles of the ocean. The movements of the waters are in the nature of creeps, and were detected by plotting vertical sections of the distribution of temperature and salinity. The results are in accord with those expected from theoretical considerations. There is a large influx of warm, salt North Atlantic water from the north side of the equator, which takes the shape of a deep-seated current occupying the depths between 1,000 and 2,000 fathoms. This influx makes good the surface movement across the equator in the opposite direction which transfers water to the Caribbean Sea and Gulf of Guinea.

This warm, salt water moving southwards begins at lat. 50° S. to approach nearer to the surface, and eventually in part supplies the heat which melts the Antarctic icebergs. The large scale ice-melting leads to two current movements. The very cold, fresh ice water, mingling with the surrounding ocean water, forms a cold, surface current of low salinity which moves northwards. At about lat. 50° to 45° this water gradually passes from the surface to become an undercurrent, sandwiched between the very warm and saline surface waters (of low density on account of their high temperature), and the intruding body of North Atlantic water already mentioned. This intermediate current of cold, fresh water can be traced as far as the equator. Round the base of the Antarctic icebergs (which may be tens and even hundreds of square miles in extent) is salt water, which is supplying heat for melting the ice. Its temperature falls very nearly to freezing point, and it sinks to the bottom as a very cold, saline body of water, which creeps northwards over the ocean floor, and determines the uniform temperature there. This bottom creep was traced northward to the equator. Thus, in all, four quite distinct zones or layers of water were distinguished—the surface waters, the cold fresh under-current, the warm, salt, deep-seated current, and the cold, salt, bottom creep.

Another area that has been studied in detail is the Norway Sea, a deep basin enclosed partly by land, and partly by submarine ridges, notably the Wyville-Thomson Ridge to the south. The picture revealed is again a complex one. A surface stream of warm, salt Atlantic water (the Gulf Stream Drift) enters the sea between Scotland and the Faroe Islands, and a great part of this water passes out of the basin between the north of Norway and Bear Island. This movement outwards is matched by a movement inwards of cold, relatively fresh water from the Polar Basin, which enters between Spitzbergen and Greenland. The greater part of this cold water issues from the Norway Sea between Greenland and Iceland as the Denmark Current.

There is, however, a modification of the circulation due to the submarine configuration of the basin. A part of the salt Atlantic water is diverted westwards, and moves in a counter-clockwise direction past Spitzbergen, gradually turning southward. Similarly, a part of the current passing Greenland is diverted eastwards by the Icelandic-Faroe (or Wyville-Thomson) Ridge, and gradually curves northwards. The chart of sub-surface salinity clearly shows this movement, which results in interlocking tongues of salter and fresher water in the centre of the basin. Various minor eddies and interlocking tongues, both in the horizontal plane and in the vertical plane, can be distinguished, and in general it appears that directions impressed upon moving bodies of water by sub-surface configuration and by the resistance offered by other moving bodies play an important part in oceanic circulation. For example, a recent study of the waters just inside the Strait of Gibraltar revealed a vertically upward movement of very salt bottom waters, guided by the upward slope of the basin and the ridge across the Strait: this was indicated by the salinity distribution, the isohalines running vertically from the submerged lip of the basin to within 70 fathoms of the surface. These results are not in harmony with the generally held opinion that warm, ultra-saline water passes out of the Mediterranean Basin into the Atlantic Ocean as an undercurrent, and that this undercurrent is the source of supply of the body of warm salt water that can be traced at a depth of about 500 fathoms flowing as an intermediate layer past the coast of Lisbon and into the Bay of Biscay. A longer series of observations, however, may reveal that now one and now another condition prevails. The same study of the western extremity of the Mediterranean confirmed the fact that where there is discontinuity of density—*i.e.*, a lighter layer of water lies upon a heavier—wave motion occurs along the boundary plane. Such waves may be oscillations set up by a disturbance at the surface, or may be tidal in character. An instrument submerged to a particular depth may, therefore, be now in the crest and now in the trough, of such a wave, when quite different results will be obtained. Thus single readings may be misleading, and observations should be repeated at intervals during the same day.

The need for a more complete and more systematic study of the ocean waters is great, if only for the light it throws on the migrations of fish, and the causes of good and bad spawning seasons, which are related to varying conditions of salinity. An unusual influx of warm water means an enormous transference of heat into an area, and this makes itself felt upon the agricultural harvest months and perhaps even a year later. Variations of salinity have been correlated with the eleven-year sunspot period, and the latter appears to be related to changes in the radiant energy emitted by the sun. An intensification of solar energy, even if slight, should accentuate the atmospheric circulation, and increase the storminess in the regular storm belts: the oceanic circulation, although lagging behind, is stimulated in its turn, while the effects of the more active ocean circulation are experienced later still. Should the links in this hypothetical chain of causation be worked out, then a prognostication of the harvest, a forecast of enormous economic value, would become a practical possibility.

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EARTHQUAKES AND VOLCANOES

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LONDON: ERNEST BENN LIMITED
BOUVERIE HOUSE, FLEET ST. E.C.

First published 1929

MADE AND PRINTED IN GREAT BRITAIN BY
BILLING AND SONS, LTD., GUILDFORD AND ESHER

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EARTHQUAKES AND VOLCANOES

PART I.—VOLCANOES

CHAPTER I

THE ASSOCIATION OF VOLCANOES AND EARTHQUAKES

Earthquakes and volcanoes have long been closely associated in the public mind. Cowper expressed the current belief of his time in the lines:

" She quakes at His approach. Her hollow womb,
Conceiving thunders, through a thousand deeps
And fiery caverns roars beneath His foot.
The hills move lightly and the mountains smoke,
For He has touch'd them. . . .

What solid was, by transformation strange
Grows fluid, and the fix'd and rooted earth,
Tormented into billows, heaves and swells,
Or with vortiginous and hideous whirl
Sucks down its prey insatiable.

. . . The sylvan scene
Migrates uplifted, and with all its soil
Alighting in far distant fields finds out
A new possessor, and survives the change."

When Cowper wrote that poem " the mountains' smoke " and the floods of molten rocks were attributed to the same cause as the heaving of the earth, the swallowing of towns and myriads of people by "insatiable" fissures, and the burial of cities beneath the fragments of exploded mountains or the transported soil of a "sylvan scene."

The association of earthquakes and volcanoes is true to some extent, for both are due to processes that take place deep below the earth's surface, and that may either cause a snap in the earth's crust and thus occasion an earthquake, or may discharge molten rock through a volcano. Earthquakes and volcanoes are often associated geographically; for they generally occur in districts that are undergoing great earth movements. The most frequent and powerful earthquakes in Europe are on the shores of Italy and of the Ægean Sea; they happen near the only active European volcanoes, except for those in Iceland; and though Lisbon, the scene of the most famous of European earthquakes, is far from any active volcano, the islands in the Atlantic opposite Portugal are volcanic in origin. Earthquakes often precede a volcanic eruption, and keep the adjacent ground quivering during their progress, while the most violent volcanic explosions shake the whole world.

Nevertheless, the association of earthquakes and volcanoes is not invariable, and is not as close as is generally believed. The main earthquakes in Italy do not devastate towns on the slopes of the volcanoes, but those on the older underlying rocks. The great earthquake of Messina in 1908 had no appreciable effect on the adjacent volcano, Etna; and many disastrous earthquakes occur in regions where there has been no volcanic activity in modern times. The association of earthquakes and volcanoes is indirect. Both are due to changes that take place deep in the interior of the earth, and both occur on the weaker and less stable parts of the earth's crust. In some of these areas the changes are relieved by volcanic action and in others by earthquakes.

CHAPTER II

THE NATURE OF VOLCANIC ACTION AND GEYSERS

Volcanoes may be considered first because they are more easily studied than earthquakes. The active volcanoes on the earth number about four hundred and thirty; their eruptions are frequent and lengthy and may be studied at leisure. Earthquakes, on the other hand, are sudden, short, and startling; and though the effects may be observed afterwards, they are often unintelligible without the records of instruments which require much technical knowledge in their preparation and interpretation.

The simple definition in Johnson's *Dictionary* of a volcano as a "burning mountain" expresses the popular idea. The glare around a volcano at night is, therefore, described as "flame"; the high column of cloud which rises from the volcanic vent and often spreads out above—to use the ordinary comparison—like a pine-tree is regarded as "smoke"; and the chief material in the hill piled up around the mouth of the volcano is usually known as "ash." This conception of volcanic action was expressed by Matthew Arnold:

"Through the black, rushing smoke-bursts,
Thick breaks the red flame;
All Etna heaves fiercely
Her forest-cloth'd frame."

The burning of volcanoes was attributed to the combustion of beds of coal, or sulphur, or of petroleum. Lemery in 1700, in a paper contributed to the Paris Academy of Science, "Sur les Feux Souterrains, les Tremblements de Terre, le Tonnerre, etc., expliqués chimiquement," supported this idea by the action of a model volcano, made by burying fifty pounds of mixed sulphur and iron filings worked into a paste with water. The swelling of the material forced up the ground above it; sulphurous vapours were discharged through the cracks, and the ground was heated; and when the vapours were ignited the fire spread underground. In 1826 Charles Daubeny, Professor of Chemistry at Oxford, gave the most scientific expression to the combustion theory. He attributed volcanic action to the effect of sea-water which sinks underground and carries air with it; on reaching the under-side of the earth's crust the water acts upon the metallic sulphides and alkalis. He claimed that such conditions would give rise to the vapours characteristic of the different grades of volcanic intensity; first hydrochloric acid, next sulphurous gases and nitrogen, later sulphuretted hydrogen and carbon-dioxide, and finally carbon-dioxide and steam.

The belief that volcanoes are burning mountains has imposed on the subject the three misleading terms, smoke, flame, and ash, which encourage an erroneous idea of the nature of volcanic action. A volcano is essentially a channel up which rock that has been melted by heat and pressure rises to the surface of the earth and is there discharged. The material is forced upwards by the gas-pressure due to the included water vapour. The nature of gas-pressure may be illustrated by a soda-water bottle; its water contains compressed carbon-dioxide which, when the bottle is opened, escapes as bubbles of gas; and their expansion forces out the water. Gas-pressure is increased by heat, so that if a bottle of soda-water is left lying in the sun in the tropics it is likely to burst. All rocks contain water, which is held within those that lie deep below the earth's surface by the immense pressure of the overlying rock. If that pressure be lessened, the water may separate as vapour, which will force any fluid rock upward, and it may overflow at the surface as a stream of molten rock or lava. Near the surface the water vapour may escape suddenly in explosions that blow the rock into fragments; and they fall around the vent in beds of tuff, while the fine powder is carried up in the steam as volcanic dust. The blackness of the clouds above a volcano is due to their being charged with this dust. The dark column above a volcano is not smoke, but is dust-charged steam. Similarly the supposed flame at a volcanic eruption is the glare reflected from incandescent material within the volcano upon the clouds above. Flames occur occasionally, and some are due to the burning of hydrogen; but such flames are usually invisible to the naked eye. The loose, cindery-looking material which is called "volcanic ash" consists of fragments of rock which have been blown up into a cellular frothy mass by the bubbles of water vapour, like the holes in bread due to the gas set free in the baking of the dough. This use of the term "ash" is as misleading as the view of some early geologists that the lavas of the extinct volcanoes of the Auvergne, in Central France, are slag heaps left by Roman iron-smelters.

Geysers.—The nature of volcanic eruptions may be understood by the action of geysers, or those hot springs that discharge their water at intervals in explosive outbursts. The nature of geyser action was suggested by a French geologist, Robert, and proved by the work of the German chemist, Bunsen, from observations on the Great Geyser of Iceland. That geyser consists of a cylindrical vertical pipe seventy-one feet deep: it is surrounded by a ring-shaped hill of sinter built up of successive layers like the crater of a volcano. This geyser mound usually encloses a pool of water which is boiling (212° F.) at the surface, when at the bottom of the pipe the temperature is 258° F. The lowest water is kept liquid, although well above the ordinary boiling point, by the pressure of the water above it. The water at the bottom is "superheated." Still hotter water trickles into the bottom of the pipe, and when the temperature there has reached 276° F. the weight of the seventy feet of water above it is no longer capable of preventing its expansion into vapour. The conversion of this water into vapour uplifts the whole column of water above it; and when water of the temperature of 255° F. rises to the depth of only forty-three feet it also bursts into water vapour, its explosion uplifting the water above it to a level at which it is also vaporized. Hence the conversion of the water at the bottom of the pipe into vapour causes the almost simultaneous change of the water in the pipe into steam. The upper water is flung out as that mixture of water vapour and drops of water which forms the ordinary visible steam.

A geyser may, then, be looked upon as a volcano which discharges only water. In some geysers and hot springs the water is so mixed with earth that they form mud-volcanoes; the material they discharge is fluid because it contains so high a proportion of water. The conditions are similar in a volcanic pipe. The water in the lower levels is prevented from expanding into vapour by the pressure, and it remains as superheated water. When it rises to a level where the pressure is insufficient to prevent its conversion into vapour, its expansion drives the molten rock upward, as it forms innumerable gas-cavities, or it may blow the lava into fragments by explosions.

The essential part of a volcano is its pipe, which provides an outlet by which surplus material from the interior of the earth escapes at the surface; as Seneca (1 B.C. to A.D. 64) truly remarked of Vesuvius, the mountain is not the source of the energy, but its channel: *non alimentum sed viam* ("it is not the food but the way").

CHAPTER III

VOLCANIC MATERIALS

THE material discharged from volcanoes consists of three main kinds—gases, including water vapour; molten rock or lava; and beds of rock fragments, of which the two most abundant classes are tuff and volcanic dust.

Of volcanic gases, by far the most important is water vapour. Some of it may be derived from rain-water or sea-water which has soaked underground and has been converted into gas by the heat of the eruption; but the bulk of the water vapour is probably of deep-seated origin and has escaped from the rock material below the base of the volcano. It is plutonic or juvenile water which is being added to the water on the earth's surface from the interior of the earth. The other gases present include various acids such as hydrochloric, hydrofluoric, boric, sulphurous, and carbonic acids, with iron chloride and sulphuretted hydrogen.

The gases ejected during the period of most intense volcanic action are hydrochloric acid, hydrofluoric acid, sulphuretted hydrogen, and often boric acid, which is discharged from Vulcano in the Lipari Islands in quantities which are worth collecting commercially. Arsenic sulphide (realgar) and selenium is often associated with the sulphur. The products of this period include many chlorides, including those of potassium, magnesium, ammonium, and common salt, as well as chlorides of iron, lead, and copper. Chloride of lead (cotunite) and copper chloride are both found in the Vesuvian lavas. The iron chloride ($Fe\ Cr_3$) is often decomposed on the surface and gives rise to small veins of iron oxide (hæmatite). The decomposition of hydrochloric acid and of steam sets free hydrogen, which burns at the surface with light blue flames; this process was first recognized in 1866 at the eruption of Santorin in the Grecian Archipelago. The decomposition of water also sets free oxygen. Nitrogen is discharged, but it may be derived from the atmosphere, for the claim from the Hawaiian Islands that as some of this nitrogen is free from argon it cannot be atmospheric has not been confirmed.

When volcanic activity begins to wane, the sulphuretted hydrogen is altered to sulphur-dioxide (SO_2), and sulphurous vapours are the predominant gases discharged. As the volcanic forces still further decline the chief gases given forth are carbon-dioxide, water vapour, and hydrocarbons, and they may continue to blow off at fumaroles or steam vents long after the volcano has become completely extinct. The vapour sequence from the gas jets known as fumaroles therefore gives a valuable indication whether a volcano is only dormant or is actually extinct. If active solfataras still discharge sulphurous gases, further eruptions are likely; but if the gas vents discharge only steam and carbon-dioxide the volcano may well be extinct.

Lava Flows.—The solid materials discharged by a volcano partly consolidate from molten material in continuous sheets of rock, and are partly discharged in fragments and powder. The compact rock occurs as lava flows, which may either spread out as broad sheets or be confined to narrow pipes, which in the eruption at Ambryn (1913) in the South Sea Islands were six miles long and thirty yards wide.* The lava solidifies on the surface into a pipe, through which runs the molten lava. An ordinary lava flow is compact in the middle, has a rough, irregular lower surface, where the rock solidifies quickly in contact with the ground, and a cellular upper surface as the escaping steam blows it into a frothy mass. This material is said to be scoriaceous or vesicular, if the rock around the cavities is earthy in appearance; it is pumiceous if the solid matter is glassy. Ordinary pumice is the frothy top of an acid lava stream. The surface of a lava sheet often has a ropy aspect, for, when flowing down a slope, the surface is raised in rope-like projections, such as may be seen on a sloping surface of pitch.

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* *Geol. Mag.*, 1917, p. 533.

Lava consolidates in two main types; if the solid crust of a lava stream is broken up by the flow, the lava may occur in great blocks. This type has been called the "Aa," a name given to it in the Hawaiian Islands. Lava streams formed as piles of boulders are known in Australia as "stony rises." Sometimes the rock solidifies with smooth rounded surfaces, and it is then known as pillow lava, a term first given to the rounded masses with the variolites of Mount Genèvre. This structure is often formed where a lava sheet flows into a sheet of water, but may be developed under other conditions. Sometimes lava is so fluid that it flows down gentle slopes and spreads out in wide sheets over a plain. Under other conditions the lava behaves like a thick paste, and consolidates on slopes of sixty degrees. The slow cooling of the centre of a lava sheet often leads to its contraction in regular six-sided columns. This columnar structure is well known in the Giant's Causeway in the north-east of Ireland and at Fingal's Cave in Staffa.

Dykes.—Some molten volcanic material solidifies underground as intrusive sheets or masses. The rock at the top of the volcanic pipe forms a solid plug at the end of each eruption. After the eruption of Mont Pelée in 1902 (*cf.* p. 33) the plug was pushed upward as a rock spire eight hundred feet high. This plug blocks the outlet up the pipe, and any further molten material forces its way through the base of the volcano as intrusive sheets or dykes. Radial cracks made by the rising material are filled by the molten rock and form dykes radiating from the pipe. Sometimes the heaving of the centre of the mountain may form concentric cracks, and the molten material forces its way up them in ring-shaped dykes which are well known in Mull and Arran. Where dykes reach the surface they give rise to secondary points of eruption, which build up secondary or parasitic cones on the flanks of a volcano. They may be on radial lines or, as in Etna, in a circular zone around the base of the main cone, an arrangement which suggests the existence there of ring-dykes around the plug.

Tuff, Dust, and Agglomerate.—The fragmentary volcanic materials are divided into three main types. The normal form is known as volcanic tuff. It consists of fragments which vary in size within the same range as nuts, ranging between those of peanuts and coconuts. When many of the included fragments are boulders more than six inches in diameter the material is known as agglomerate. The boulders are sometimes many cubic yards in size, and such ejected blocks are evidence of the immediate proximity of an explosive volcanic centre. Farther from the centre the blocks become smaller and the agglomerate passes into tuff. The finest material is the volcanic dust. It may be carried up by the escaping steam in a column to the height of thirty miles above the mouth of the volcano. The dust-charged column of steam may spread out above and thus give rise to the form generally compared to a pine-tree. The dust at high levels is often carried by the winds two or three thousand miles away from the volcano; and after the eruption of Krakatoa in 1883 the volcanic dust was spread worldwide and gave rise to brilliant glowing red sunsets throughout the world. Some of the ejected material falls in rounded masses which are known as volcanic bombs. If they are cellular inside and have a compact rough crust, they are known as bread-crust bombs. In some eruptions the material is broken up into small fragments of material so full of air cavities that it is light and floats on water; this pumice drifts across the oceans for great distances before it becomes water-logged and sinks.

CHAPTER IV

VOLCANIC CONES AND CRATERS

The solid material ejected by a volcano is piled up into conical or ring-shaped hills round the vent. In some volcanoes nearly all the solid material is discharged as lava, which builds up lava-cones. As a rule the lava sheets are interbedded with layers of tuff. Cones composed wholly of fragmentary material are described as tuff-cones. Most volcanoes are composite-cones composed of both lava and tuff. The cone usually has a central hollow known as the *crater*, which lies above the mouth of the volcano. The crater is often breached as the rising column of lava breaks through the side, and pours as a lava stream through the breach. Sometimes the weight cracks the base of the mountain, and the molten rock then fills the fissures and consolidates in them as dykes. Some of the dykes may reach the surface and give rise to secondary craters.

Volcanic craters are of three main types. Ordinary craters are hollows left by the building up around the mouth of a ring-shaped hill which is composed either of lava or tuff. Explosion craters are hollows formed by volcanic explosions, such as the crater around the modern cone of Vesuvius, or the great explosion crater of Katmai in Alaska, which was formed on June 6, 1912, when an explosion blew the upper part of the mountain, five cubic miles in bulk, into the air, leaving below the former summit a pit three miles in diameter and three thousand seven hundred feet deep. The third kind are subsidence craters or volcanic caldrons, the equivalent of the Spanish word *caldera*. The central parts of some volcanoes have been replaced by a depression which, as in the case of Aso in Japan, is twelve by fourteen miles in diameter. The caldron of Ngorongoro in East Africa is twelve by eleven miles in diameter and surrounded by steep walls up to two thousand feet in height; it has a lake four miles long upon its floor, which is over one hundred square miles in area. The hollow containing the lake Lago di Bolseno in Italy (ten and a quarter miles in diameter), the crater of Santorin in the Greek Archipelago (ten miles by eight across), and the Crater Lake in Oregon (five and a half miles in diameter), are probably also caldrons.

Another type of hollow which has been described as a crater is the impact crater, made by the fall of a meteorite. According to Haidinger, a meteorite weighing six hundred and sixty pounds, which fell at Kynahinya in Hungary in 1866, made an impact crater four and a half feet deep and four feet in diameter. The "Meteor Crater" in Arizona is a pit from four hundred to six hundred feet deep and three-quarters of a mile in diameter. It is in an area of sandstones with no evidence of volcanic action in the neighbourhood; the nearest igneous rock is several miles distant. The rock on the sides of this pit have been pushed outwards, and at two places on opposite sides the ground is scattered with huge blocks of sandstone, which appear to have been squirted out of the pit in consequence of a tremendous blow. Many scattered blocks of an iron meteorite have been found along a track at right angles to the direction in which the sandstone blocks have been flung out of the pit. As these meteorites are composed of iron and nickel and contain platinum and other valuable metals, efforts have been made to reach and mine the meteorite which is believed to have made this pit. A boring on the floor to find the meteorite passed through layers containing quartz grains that have been smashed and cracked and mixed with nickel-iron sand. This material looks like sandstone that has been crushed by the fall of the meteorite and mixed up with grains torn from it. A block of material that was too hard to pierce by boring has since been found, and work is in progress to reach it by a shaft and mine it. This meteorite fell in times which for Arizona were prehistoric. Another colossal meteorite fell in Siberia on June 30, 1908. It buried itself in the ground north of the Stony Tunguska River in about longitude 102° W., and north of latitude 60° N. Its fall created a hot blast which scorched the forest and tore off the treetops for miles around (*cf*. L. Kulik, *Pet. Mitt.*, vol. lxxiv., 1928, pp. 337-341).

CHAPTER V

PERIODIC VOLCANOES

VESUVIUS AND ITS VOLCANIC HISTORY

THE nature of volcanic activity can be best appreciated by the study of representative volcanoes. Vesuvius is the most famous, and is the type of the class known as the periodic, because its eruptions are separated by periods of quiescence. The earliest known accounts of Vesuvius show that in classical times it was a dome-shaped mountain, and had at the summit a broad hollow with walls clad with wild vines, and with a lake on the floor. The rebellious gladiators led by Spartacus took refuge in this natural stronghold in B.C. 72, and were besieged by a force of three thousand men. There was then no record or tradition of the mountain having been in eruption, though the geographer—Strabo—recognized from the nature of the rocks that Vesuvius "had emitted fire in ancient times." Vesuvius had been built up by prehistoric eruptions, which had formed a mountain about ten miles in diameter, thirty miles in circumference, and covering an area of about seventy-five miles. For at least a thousand years Vesuvius had lain dormant, and danger was first indicated on Feburary 5, A.D. 63, when an earthquake overthrew the city of Pompeii at its southern foot. The city was rebuilt, but a succession of earthquakes shook the neighbourhood, and their increasing strength roused alarm. On August 24, A.D. 79, after a particularly violent earthquake, the central part of the mountain was blown to pieces by an explosive eruption. Part of the old base was left as the crescentic ridge known as Monte Somma, that now forms the northern rim, and the Observatory Ridge on the western side. In the hollow formed by the explosion the modern cone of Vesuvius was built up, and has been the site of all its later eruptions. Vesuvius is a much smaller mountain than its predecessor, of which Monte Somma is a remnant. Modern Vesuvius is only one and a half miles in diameter; its height is about four thousand feet above sea-level, and varies from one thousand five hundred to one thousand eight hundred feet above its base; its crater is about eight hundred by five hundred yards in diameter, or about half a mile in circumference. The bulk of the mountain is probably only one-eightieth of that of the original cone of Monte Somma.

The details of the first historic eruption are known from the account by the younger Pliny of the death of his uncle, the Roman admiral. As the escape of the inhabitants from some places near Pompeii had been cut off, the elder Pliny went to the rescue. He reached Pompeii, and, while resting there that night, the volcanic materials fell so heavily on the town that it was fast being buried. His guard woke the snoring admiral and, with pillows on their heads as protection from the falling stones, they returned to the shore to see if the waves that had been flung up by the earthquakes had become less violent and boats could put to sea. There the gallant admiral died. According to the report he was suffocated by poisonous fumes from the ground, though the account suggests that he died from exhaustion and heart failure. Pompeii was completely buried under volcanic dust and tuff; and as some of the stones, six miles from the vent, weighed eight pounds they must have been hurled to a height estimated as fourteen thousand five hundred feet. Herculanean, at the western foot of the mountain and only four miles from the vent, was buried more deeply under a sheet of mud as the torrential rain that accompanied the eruption washed dust from the air and down the slope of the mountain. No lava appears to have been discharged, and the description by the younger Pliny of a dark cloud "which came rolling after us like a torrent" recalls the down-rush of volcanic dust clouds from Mont Pelée in 1902 (*cf.* p. 33).

This eruption was followed by a long period of quiescence, interrupted by eruptions in A.D. 203 and 472; the latter was reported to have "covered all Europe with fine ashes"; the volcanic dust appears to have been carried by the wind in such quantities as far east as Constantinople that the darkness caused great alarm there. Minor outbursts in 1036 and 1049 were followed in 1139 by the first of the recorded eruptions, which discharged great lava flows, and some of them then reached the sea. Small eruptions occurred in the years 1306 and 1500. Then followed complete quiescence for one hundred and thirty years, during which the crater, a mile and a half wide and one thousand feet deep, was covered by forest inhabited by wild boars, and the floor was occupied by cattle and pools of hot water. After this long rest a series of violent earthquakes heralded the eruption of December, 1631, during which four vast lava streams flowed down the western slopes and reached the sea five miles distant. Volcanic dust was again blown eastward to Constantinople.

Since 1631, Vesuvius has had no long period of quiescence. There have been eruptions every few years, and some of terrific violence at longer intervals. The most important eruptions were in 1660, 1682, 1685, 1698, 1701, 1766-7, 1779, 1794, 1822, 1831, 1839, 1850, 1855, 1858, 1872, and 1906. The lava streams at some eruptions reached the shore, as in 1794, when they overwhelmed the town of Torre del Greco, and the volume discharged is said to have been three hundred million cubic feet. The total amount of material thrown out by Vesuvius in its historic eruptions is estimated at four times the bulk of the mountain.

The volcanic history of Vesuvius has been remarkably uniform throughout its history. The lavas have all been similar in composition. Their most conspicuous constituent is a comparatively local white mineral known as leucite, and Vesuvius is composed of leucite-lava and leucite-tuff. The rocks differ from those of Etna by containing a larger proportion of soda, and must be discharged from a reservoir of different material and probably from a different zone in the earth's crust. The Vesuvian lava has greater explosive power than that of Etna.

The nature of the eruptive activity of Vesuvius has always been the same—long periods of quiescence with occasional paroxysmal eruptions. The work of Johnson-Lavis at Monte Somma (1874) has shown that the prehistoric volcano had also been built up by explosive eruptions with prolonged intervals of repose.

The Volcanic History of Etna

Etna is also a periodic volcano, and its eruptions have happened at more regular intervals than those of Vesuvius. Its eruptions are less explosive and are characterized by the discharge of vast streams of lava. But although the proportion of tuff to lava on Etna is smaller than on Vesuvius, the tuffs in some modern eruptions are estimated as constituting two hundred times the bulk of the lavas.

Etna is the biggest of European volcanoes, and has been longer in eruption than any other on record. Its history begins with the dawn of classical literature, at about 800 B.C., for Homer's reference to the giant, one-eyed Polyphemus, who pelted Ulysses with blocks of stone, was probably an allusion to Etna. Thucydides recorded an eruption in 693 B.C. The description in 475 B.C. by Pindar, in one of his Pythian Odes, of an eruption of Etna shows that they then followed the same general course as in modern times. According to Diodorus Siculus, a lava flow from Etna, twenty-four miles long by two miles wide, in 396 B.C. stopped the advance of an invading Carthaginian army. Twelve eruptions are recorded before the beginning of the Christian era, and five in the next six centuries. Then, after a long gap, the history began again with the Norman conquest of Sicily, in the eleventh century.

The base of the mountain consists of an enormous dome which covers four hundred and sixty square miles and is ninety miles in circumference. It rises with a long, gentle slope, which for about ten miles has an average slope of one in ninety, and the lavas and beds of tuff are so decomposed that they form the rich soils which support the dense population of Etna. Above this zone, from the level of about six thousand feet, the slope steepens for about five miles, and then the central cone of tuff rises with the steep gradient of one in six to the summit, which varies from between ten thousand seven hundred and ten thousand nine hundred feet. This tuff-cone is now never reached by lava, but is frequently altered by explosive eruptions of steam.

The Val del Bove is a great subsidence hollow near the base of the tuff-cone. This valley is five miles long and from two to three miles wide, and its floor is thirteen square miles in area. It has been regarded as a crater due to an explosive eruption, or as having been cut out by streams; but as explained by Lyell it is doubtless a caldron due to the subsidence of its floor.

The most striking feature of Etna is the importance of its secondary volcanic cones; they number about two hundred, and some of them elsewhere would be counted as large primary volcanoes. They occur in a zone around the base of the central cone, and are doubtless due to its weakness. The lava column in the base of the mountain is surrounded by a thick-walled pipe, which is strong enough to hold the column of molten rock; but the upper cone is thinner and weaker; and before the lava column has reached the crater at the summit of the volcano its weight bursts the walls of the pipe and produces fissures that reach nearly to the surface. From points along the fissure the lava escapes and builds up secondary or parasitic cones.

The most recent eruption of Etna, in November, 1928, is typical of its activity. It began on November 2, when a column of steam was seen from Catania, and during the next two days a series of vents from a fissure opened down the side of the mountain. On the night of November 4 a large vent opened on this fissure at Ripe del Anaca (three thousand four hundred feet), and a great stream of lava from it drained the whole of the upper part of the fissure, and the higher vents were closed. A block-lava or Aa stream destroyed the town of Mascali; it advanced about fifteen feet an hour as a sheet twenty-five feet thick, and pushed buildings over as its weight piled against them. One lava stream from Anaca was six hundred and fifty yards wide and ten miles long; it cut the two railways and the roads near the coast, and reached the sea. A still lower vent was opened on November 8 and discharged a stream that flowed nearly two miles a day and threatened the town of Giarre. The eruption had practically ceased by November 13; by that date the lava had covered one thousand eight hundred acres of orchards, olive groves, and vineyards, and destroyed property estimated at £2,000,000.

The eruptions of Etna are, as a rule, more destructive of property than of life, for they are not explosive and the lava generally flows slowly and people can retreat betimes. The lavas from the earliest days to the present have maintained a remarkable uniformity.

They are andesitic basalts, and are all very similar in chemical composition. They contain no leucite, the characteristic mineral of Vesuvius. The only notable variation is that some of the ancient lavas around the Val del Bove are phonolitic. The character of the eruptions has also been conservative, and throughout historic times Etna has maintained its periodic eruptions with remarkable persistence. Probably Etna was less active in the first millennium A.D. than it has been since, but the mountain was probably in intermittent eruption throughout it.

The list of eruptions is fullest in recent centuries, no doubt in part because the records are more complete. From the sixteenth century the eruptions have occurred on an average of one in every six years, exclusive of the small steam eruptions which are constantly happening in the great crater; but there appears to be a sound basis for the impression that Etna, like Vesuvius, had a long spell of lesser activity in medieval times, and has been more active since the sixteenth century. This contemporary change in activity, in spite of the eruptions of the two centres having seldom been simultaneous, indicates that both mountains respond to a change which affects the whole of the region around Southern Italy.

It has been suggested from a formula, and from the fact that the ejected blocks in Monte Somma include limestones and other rocks from the platform immediately underlying Vesuvius, that its material is discharged from reservoirs about three thousand feet below sea level. The same depth is assigned to the South Italian volcanoes. . The absence of deeper-seated rocks from the ejected blocks of Vesuvius may be due to their having been melted, as they would have been included for a longer time and in hotter lavas. The general evidence suggests that the eruptions are due to forces acting at a much greater depth than three thousand feet, and probably not less than twenty miles deep.

The deep-seated origin of their activity is indicated by the comparison of Vesuvius with other Mediterranean volcanoes. Vesuvius is two hundred and fifteen miles from Etna, and if their energy were generated at the depth of only half a mile they should be wholly independent in action. During certain periods Etna and Vesuvius appear to have been totally disconnected. Etna was in eruption ten times in the five hundred and twenty years between 480 B.C. and A.D. 40, and Ischia had violent eruptions in the fifth, third, and first centuries B.C. During all this time Vesuvius was quiet. Etna was in eruption in the ninth, thirteenth, and fifteenth centuries, and Stromboli was active all the time, while Vesuvius was dormant; Etna was inactive during the Vesuvian eruptions of the eleventh and twelfth centuries. This apparent lack of sympathy between Vesuvius, Etna, and Stromboli, and the extinction of the northern groups in Tuscany, near Rome, and on Ischia, may suggest that their activity is local and independent. But a more general survey indicates that all the Italian volcanic centres, though very irregular in their periods of activity, have a correspondence that indicates some common connection.

During the long rest of Vesuvius, for five or more centuries before A.D. 79, the frequent eruptions of Etna and the Lipari Islands apparently provided adequate outlet for the subterranean energy. The terrific explosion of Vesuvius in A.D. 79 appeared to relieve the pressure, and then followed a long period of comparative quiescence throughout the Italian volcanic area. Eruptions occurred at intervals, and Stromboli no doubt maintained its slight, superficial activity. After the eleventh century the violent outbreak of the Solfatara in 1108 was followed by a time of more frequent eruptions; and after 1631 Vesuvius and Etna, seldom together, have been repeatedly active.

A general survey indicates that the activity of Etna has at some time relieved the volcanic activity of the region, and after it was restimulated in 1631 it has been relieved by either Etna or Vesuvius; and rarely have both been in eruption at the same time. This correspondence implies that the two volcanoes are dependent upon conditions that are miles deep, so that the stress of deep-seated source gains relief by vents two hundred and fifteen miles apart.

The fact that the vast mass of Etna has been piled up on one corner of Sicily without causing its subsidence shows that it is resting on a thick foundation; for if all the materials had been discharged from only a few thousand feet deep, the weight would probably have broken the arch of the crust above the reservoir. The explosions of Vesuvius in the years 79 and 1631 must have been confined in a long tube, or they would probably have made a larger surface rupture, as in the explosions of Krakatoa and Tararewa (Chapter VII.).

Kilauea, in the Sandwich Islands

Kilauea, in the Sandwich Islands, affords a striking contrast to Vesuvius and Etna by the non-explosive character and regular periodicity of its eruptions. The Sandwich Islands are a volcanic group in the North Central Pacific. The rocks are mainly basalts. The largest island—Hawaii—rises as a low dome-shaped mass to two summits—Mauna Kea, thirteen thousand and eighty-five feet, and Mauna Loa, which reaches the height of thirteen thousand six hundred and seventy-five feet by a gentle slope of about ten degrees. To the south-east of Mauna Loa, at the height of four thousand and forty feet, is the comparatively shallow pit of Kilauea, famous for its lava lakes and gentle eruptions.

On the visit of J. D. Dana in 1840, the pit of Kilauea was four square miles in area, six hundred and fifty feet deep, and had three lakes of molten lava on its floor. The pit is gradually filled by the rise of lava, which is discharged by eruptions at intervals of usually from eight to nine years. Each eruption consists of a quiet overflow of the lava in streams, which sometimes reach the sea eleven miles distant. The eruptions are attended by only a few and feeble explosions, and the discharge of but a small quantity of steam. Minor explosions happen from some subsidiary vents from which the outlet is smaller. After an eruption the pit is renewed by the collapse of its floor. As the pit is made by subsidence, it is a volcanic caldron and not a crater. The remarkable regularity of the eruptions of Kilauea is due to the slow up-squeezing of molten material into the caldron. This process goes on at a fairly regular rate, and thus the caldron is periodically filled and emptied.

CHAPTER VI

CONSTANT VOLCANOES

Stromboli, on the Lipari Islands, is the type of a third class of volcano—those that are constant in activity. Stromboli is a small, isolated volcano that occupies an island off the northern coast of Sicily. Its constant activity, though slight, has apparently been almost continuous through historic times. The volcano was in its present condition in the time of Strabo (63 B.C.–A.D. 21), and it has been aptly called the Lighthouse of the Mediterranean. The glare from it at night was a useful guide to the entrance to the Straits of Messina.

A few years ago Stromboli became dormant for about a year, but it has resumed its chronic activity. A cloud consisting of steam with dark, bead-like balls is often seen on passing the vent, and these balls are seen to be due to masses of dust thrown up by explosions, which occur at the rate of about two to the quarter-hour, the ordinary Strombolian rate. The eruptions are usually harmless, but occasionally they are sufficiently powerful to compel the inhabitants to shelter in adjacent islands.

The differences between these volcanoes and their cause may be understood by reference to the previous history of the Tyrrhenian Sea, that triangular part of the Mediterranean which lies between Corsica and Sardinia on the west, Italy on the north-east, and Sicily on the south. This sea formerly was a land known as Tyrrhenis, across which animals roamed freely from Sardinia to Italy. The subsidence of this area caused such heavy pressure on the hot, fluidible rock below that some of the material was forced through the fractures around the sinking block and gave rise to the Italian volcanoes. While the main subsidence was taking place, volcanic action was more widespread than it is to-day, and volcanoes were active also around Rome and in Tuscany. The northernmost were the five volcanic centres in Tuscany, of which the best known is Monte Amiata. The eruptions were non-explosive and quietly poured forth lava flows a little over two miles long. These eruptions were confined to Lower Pleistocene times. Further south the volcanic groups around Rome were larger, but they also are now extinct. They were largely built up by great explosive eruptions which have spread volcanic tuffs twelve miles from the vents, or six times as far as the range of the Tuscan lava flows. The four Roman groups cover one thousand six hundred square miles, or ten times the area of the Tuscan group, and are the most extensive volcanic series in Italy. The eruptions built up the Alban Hills south of Rome, and contain a series of famous lakes, which lie in hollows around the volcanic vents. These eruptions began probably about the same time as those of Tuscany, but lasted till early historic times, for their activity has been recorded by Livy.

Further south the eruptions due to the subsidence of the Tyrrhenian Sea have continued later. Vesuvius is still in the explosive condition of the Roman volcanoes before their extinction. The constant activity of Stromboli probably indicates that it is on a fissure along which earth movement is still taking place, and the extensive lava flows of Etna indicate that they are being fed by material displaced by the still-sinking floor of the Mediterranean beside Southern Italy. The eruptions of Stromboli, on the other hand, have continued without serious interruption for twenty centuries; hence it must be on a fracture which has been kept constantly open. It is doubtless on a cross-fissure radial from the Tyrrhenian subsidence, and, as it is beside the sea, surface waters may percolate down the fissure and be converted into steam. The conditions at Stromboli therefore give rise to a constant succession of feeble explosions at a slight depth.

CHAPTER VII

PAROXYSMAL EXPLOSIVE VOLCANOES

THE traditional view, which was especially advocated by J. D. Dana, attributed volcanic explosions to surface water sinking underground and being there converted into water vapour. The frequent occurrence of volcanoes on islands and beside coasts is consistent with this hypothesis, which is, however, untenable for the great bulk of volcanic steam. Lavas arise from depths far below the zone to which waters can descend from the surface. Water is an essential constituent of nearly all rocks, and volcanic steam is probably as plutonic in origin as the other rock constituents discharged from volcanoes. Volcanic explosions happen, however, at comparatively shallow depths, and their water may be largely derived from rain or from the sea. Such explosions may be illustrated by the examples of Krakatoa and Tararewa.

The East Indian Islands, or Eastern Archipelago, lie south-east of Asia and extend from the Malay Peninsula to the north of Australia. These islands were, no doubt, once part of a continuous land which had been broken up by subsidence of the intervening areas along fractures; and, as in Southern Italy, volcanic eruptions have taken place along the fractures. The East Indian continent was traversed along its southern border by a continuous mountain chain, which has been broken up by straits formed at the fractures across it. In the Strait of Sunda that separates Sumatra and Java a group of three islands are the stump of an old volcano that was eight miles in diameter. The largest of the three islands is Krakatoa. It was five miles long by three miles wide and rose to the height of six thousand and twenty-three feet. A volcanic eruption happened on the island in 1680, and it was followed by two centuries' quiescence. Early in 1883 Krakatoa was shaken by violent earthquakes, and on May 20 a tall pillar of steam rose from some steam vents. Moderate volcanic eruptions continued till August 26. Then a sudden explosion hurled a column of steam to the height of seventeen miles. It was followed next morning at 5.30 and 6.44 by two violent explosions, and then at 10 a.m. (August 27) the most violent of recorded volcanic explosions blew the island into fragments. A slighter explosion happened at 10.52 a.m., and the eruption then became less active and ceased on August 29. The explosion replaced the island of Krakatoa by a trench nearly eight miles long and one thousand feet below sea-level; and the remnants of the island had cliffs one thousand feet in height. The earthquake wave formed by the explosion devastated the adjacent islands and drowned thirty-six thousand four hundred and seventeen people. The air blast overthrew the gasometers at Batavia in Java one hundred miles away, and travelled more than once round the world. The sound was heard by lighthouse keepers on Rodriguez Island, two thousand nine hundred and sixty-eight miles to the west, and at

Alice Springs in Central Australia, two thousand two hundred and fifty miles to the south-east. The pumice thrown out blocked the Strait of Sunda, so that navigation through it was closed for months. The pumice drifted in shoals across the Indian Ocean, and eighteen months afterwards was thrown up as beaches along the eastern coast of Africa. The fine dust was blown to the height of twenty-five or thirty miles and was then spread by wind throughout the world. The sunsets in November and December of the same year in the British Isles were of wonderfully brilliant and vivid tints. The first suggestion to explain them was that the earth was passing through a part of space charged with the dust of an exploded world. Some of the dust was collected and sent to Judd, who found that it contained particles of hypersthene. As Krakatoa consists of hypersthene-andesite, this discovery left no doubt that the sunsets were due to dust scattered worldwide through the higher reaches of the atmosphere by the explosion.

After this eruption Krakatoa remained quiescent until December 29, 1927, when an eruption began in the middle of the deep pit made by the explosion of 1883. It became more powerful in January, 1928, and took place from six submarine vents. The adjacent sea was rendered boiling. Volcanic bombs were thrown occasionally to the height of four thousand feet, and on January 26 the rim of a crater was raised above sea-level. It was, however, shortly afterwards swept away by the waves. This eruption ceased in February, with slight renewals later in the year.

The Krakatoa eruption of 1883 was very different from those of Vesuvius and Etna. The Krakatoa lava contained so much water that, when heated in the blow-pipe, the rock bubbled up into froth. The base of the mountain was doubtless saturated with water, which had combined with the lava and tuff. When some molten rock was forced up the pipe of the volcano the water was first superheated and then converted into gas. The first explosions rent the base of the mountain and quickened the uprise of the molten rock and superheated water, and thus led to the final explosion, which, instead of being concentrated by the pipe and thus blowing off the top of the mountain around the vent, tore out a long submarine trench. The explosion was therefore comparatively shallow, and the water which caused it may have been largely superficial.

Another famous paroxysmal eruption occasioned the tragic destruction in 1902 of St. Pierre and of its whole population. Mount Pelée stands beside the town of St. Pierre, the capital of Martinique, one of the Lesser Antilles. This chain of islands forms the crest of the ridge between the Atlantic and the Caribbean Sea. The islands on the western or inner side are lofty volcanoes, while those on the outer or eastern side are low and flat-topped, and consist of limestone. The West Indian Islands, according to one view, are remnants of an ancient continent that has been called Antillia, which was traversed by mountain chains running west and east. Remnants of these mountains form the northern range in Trinidad, which is continued westward along the northern coast of Venezuela, and also the parallel ranges in Jamaica, Cuba, Haiti, and Porto Rico. These islands rest on a foundation of old rocks, the Primeval or Pampaleozoic, and upon them rest Cretaceous limestones, as in Jamaica and Trinidad. The absence of rocks of the intervening ages indicates that most of the area had been a continuous land, which was broken up in geologically recent times by the foundering of blocks of the crust. These subsidences formed the Gulf of Mexico, the Caribbean Sea, and the depression north of Porto Rico, which is the deepest known part of the Atlantic Ocean. The West Indian islands are mostly due to faulting along on lines that run mainly east and west. The movements along the faults are still in progress, as is proved by the disastrous earthquakes that now and again devastate these islands. On March 26, 1812, Caraccas, the capital of Venezuela, was destroyed by an earthquake, and ten thousand of the inhabitants perished in the ruins. On April 27 in the same year the mountain in St. Vincent known as the Souffrière, from its sulphur-yielding solfataras, suddenly burst into eruption. The inhabitants of Barbados, over one hundred miles to the west, heard the explosions and thought that a battle was taking place between the French and British fleets; but soon Barbados was plunged into utter darkness by a canopy of volcanic dust which had been carried eastward by a high wind, while the low level wind was blowing in the opposite direction.

In 1902 the cycle of events was somewhat similar. On April 18 a powerful earthquake to the west of the Antillian region overthrew the city of Quezaltenango, the commercial capital of Guatemala. On April 23 a column of steam arose from Mount Pelée, which was regarded as extinct, as its only known previous activity had been slight eruptions in 1762 and 1851. On April 28 violent earthquakes occurred in St. Vincent, and on May 7 its Souffrière burst into eruption and devastated the adjacent districts; the local Caribs, the aboriginal inhabitants of the West Indies, had been collected into a reserve in part of St. Vincent, and they were exterminated. The death-roll on the island was one thousand six hundred. At 7.50 the next morning a terrific explosion on Mount Pelée in Martinique hurled an avalanche of incandescent volcanic dust on to St. Pierre. It swept on to the city at the speed of ninety miles an hour. The walls standing across the path of the blast were overthrown, but those in its direction were left standing. The whole population, numbering about thirty-two thousand, perished with the exception of two men who survived in the sheltered cells of the local gaol. A British ship, the *Roddam,* had just entered the harbour and anchored. The captain was talking to the agent, who had just gone aboard, when the cloud swept down from Mount Pelée. When the avalanche struck the harbour an American cable ship turned turtle and all the vessels were sunk except the *Roddam*. There was no time to lift her anchor, so the chain was let loose, and with the engines reversed the captain backed out of the harbour, steering with his elbows after his hands were too blistered to hold the wheel, and, scorched by the blast, she carried to St. Lucia the news of the disaster.

The temperature of the volcanic dust when it reached the *Roddam* was shown since it set fire to cotton goods, but not to things made of wool or hemp, unless they were smeared with oil. The captain's woollen clothes were scorched, but those of the agent, who was wearing white cotton drill, were set on fire. He jumped overboard, but perished, as the water had been rendered boiling by the hot dust. A similar later explosion happened when Sir John Flett and Dr. Tempest Anderson, who went out to investigate the eruption, were crossing the harbour of St. Pierre. Dr. Anderson photographed the advancing cloud, but it had fortunately lost its force and had cooled considerably before it reached the boat.

When the news of the disaster was received, it was attributed by some authorities to an explosion of gas which had been discharged from the volcano. The full evidence shows that it was an explosion due to steam. Unluckily, owing to the structure of the mountain, the whole force of the explosion was directed through a rent in the side downward on to St. Pierre. The destruction, though complete on the band swept by the avalanche of hot dust, was sharply bounded. The plantations just outside the town were uninjured, and the dust discharged was limited and local. The force of the explosion, however, was so violent that it shook the whole world, and some hours afterwards Melbourne Observatory rose and fell on waves about eighteen inches high, though, as they were forty miles long, they were imperceptible except to recording instruments. Subsequently, while Mount Pelée was still steaming, a tall spine of lava eight hundred feet high was forced upward from the volcano, as a cork might be pushed out of a bottle. This spine was photographed repeatedly, but it fell to pieces before the mountain cooled down sufficiently for it to be reached. Subsequently, on January 14, 1907, a disastrous earthquake seriously injured Kingston, the capital of Jamaica, and was doubtless due to further subsidence of the floor of the Caribbean Sea.

The disastrous eruptions at St. Vincent and Mount Pelée may be attributed to the subsidence of the floor of the Caribbean. Earth movements which produced severe earthquakes in the southern and western part of the Caribbean—at Caraccas in 1812 and Guatemala in 1902—were followed three weeks or a month later by volcanic eruptions on the eastern border of the sinking area. The subsidence of the floor appears to have forced the molten rock up the adjacent fissures and produced the eruptions of St. Vincent and Mount Pelée. The tragedy was due to the force of the explosion being directed downward on to the doomed city of St. Pierre. No worse fate could have befallen it had it been on the floor of a volcanic crater in full eruption.*

CHAPTER VIII

FISSURE AND PLATEAU ERUPTIONS

ORDINARY volcanoes consist of a circular mountain, which is conical or dome-shaped because the lavas and tuffs are spread around the vent; the surface is kept moderately even, as the lava streams fill in the valleys left between the preceding flows. The volcanic vents tend to occur on lines, since the eruptions take place at weak points along fissures in the earth's crust, and long fissures that have been filled by molten rock are well known. In the Midland Valley of Scotland, for example, some of these east-to-west dykes extend across country for distances of forty to sixty miles. Some volcanic eruptions are known to be fed by fissures, as at Skapta Jokul in Iceland and on the flanks of Etna. In various parts of the world the lava plains are far larger than could be formed by discharge from a single vent. In North-Western India the sheets of lava known as the Deccan Traps cover two hundred and fifty thousand square miles, and, as they are thickest behind the coast near Bombay, they doubtless extend westward under the Arabian Sea, and it is not an unreasonable estimate that their area on the ocean floor is equal to that on land. If so, these basalts would extend over an area of half a million square miles. There are no volcanic cones in the Deccan comparable to such lava sheets. The volcanic plains, moreover, consist mainly of lavas, and tuffs are less conspicuous. Similar conditions are apparent in the Great Snake River lava plains of Idaho; they are part of basalt sheets that have been estimated to cover an area larger than France and Great Britain combined, and to have an average thickness of two thousand feet (A. Geikie, *Textbook of Geology,* 1893, p. 256). The wide extent of columnar basalt shows that the upper vesicular layers of these lavas have been worn away. There are no craters corresponding in size to such immense lava sheets.

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* For references see *La Montagne Pelée et ses Éruptions,* A. Lacroix (Paris, 1904); *Tragedy of Pelé,* Geo. Kennan (New York, 1902); Tempest Anderson and J. Flett, *Phil. Trans. R. Soc.,* Ser. A, vol. 200, 1903, pp. 353-533; *ibid.,* vol. 208, 1908, pp. 275-332.

These facts led the distinguished physical geographer, Baron von Richthofen, to suggest that the lava sheets of the Snake River and India were discharged from fissures that may have been hundreds of miles in length, and, according to some suggestions, may have been several miles wide. From such outlets the lava would well forth quietly without the explosions that happen when lava is forced by steam pressure through a narrow vent and without the formation of widespread layers of volcanic tuff. Von Richthofen also suggested that volcanic activity on the earth is now dwindling, and that modern cone volcanoes are comparable to the secondary cones formed around gas vents on the surface of a lava flow, and that the change from fissure-eruptions to cone-eruptions indicates the passing of activity to the extinct condition of that on the moon.

The existence of fissure-eruptions has, however, not been confirmed. The eruption of Skapta Jokul in Iceland in June, 1783, was, it is true, from a fissure miles in length, and, according to Tempest Anderson, ten feet wide, but the lava was discharged through a series of volcanic cones and not directly from the fissure. Similarly in Etna the molten rock in the pipe ruptures the sides of the mountain and rises through the fissures, but it is discharged from isolated points along them. The fissures feed the craters, but the discharge takes place at vents, around each of which is built up a secondary volcanic crater. Small fissure-eruptions happened at Ambryn in 1913 (*Geol. Mag.*, 1917, p. 534).

It has been suggested that the basalt sheets of Mull and Skye were due to fissure-eruptions through the vertical dykes, but the evidence in support of that idea was overthrown when it was proved that the dykes are later than the sheets and cannot have fed them. There is nothing to show that the lavas of the Hebrides were discharged through fissures instead of through ordinary vents.

The Deccan Traps at Mahableshwar and Ajunta have abundant tuffs associated with the lava sheets. The tuffs are more easily decomposed and swept away, so that they are less conspicuous and most of the surface is occupied by the more resistant lavas.

The extent of the volcanic plains in Victoria, west of Melbourne, led to their explanation by fissure-eruptions. Gold mining in the gravel under these lavas has revealed the existence of a few dykes, but nothing to indicate discharge from fissures. The lava plains were formed of confluent sheets from a large number of scattered craters. Similarly the great lava sheets of East Africa are associated with abundant tuffs and many volcanic necks—the worn-down stumps of old craters from which the lavas were discharged. These great lava sheets were discharged from many vents, of which the lavas and tuff have joined into continuous sheets. The formation of numerous scattered vents may be expected on plateaus, where either by uplift or by the subsidence of the surrounding country the surface is broken by a network of cracks. If a reservoir of molten rock underlies such a fractured plateau, the lava would be discharged from the many weak points where the cracks intersect. The eruptions would be through many small vents and not from a few large volcanoes. The lava plains thus formed have been described as plateau-eruptions instead of fissure-eruptions (*Great Rift Valley,* 1896, p. 219).

CHAPTER IX

THE DISTRIBUTION OF VOLCANOES

The distribution of volcanoes throws important light on the cause and nature of their action. In dealing with modern volcanism it is necessary to consider not only the four hundred and thirty volcanoes of which eruptions have been recorded, but those which have been in action in geologically recent though prehistoric times; for it is difficult to determine whether a volcano with a well-preserved cone and crater is really extinct. Fujiyama in Japan, famous for the beauty of its cone, has been quiescent for two hundred years. But Paloeweh in the East Indies appeared extinct until it burst into eruption in August, 1928; and the history times, though arguments by Bonney that their last eruption was as late as the fifth century A.D. have not convinced the leading French experts. The volcanoes of the Rhineland and Southern Germany are in isolated groups, belonging to the same class and date as those of the Auvergne.

On the eastern coast of the Atlantic the only active volcano is that of the Kameruns, which was seen in action by the Phœnician Hanno, and has been in eruption more than once in the present century. It marks one end of the volcanic chain which continues through the islands of Fernando Po, Princes Island, St. Thomas, and Annobom. The islands of the Eastern Atlantic, except for the British Islands and those of France, are all volcanic, including the Azores, Canaries, Cape Verde Islands, St. Helena, Ascension, Gough Island, and Tristan d'Acunha. Most of the islands on the American side, such as Bermuda, St. Paul's Rock, the Falklands, and South Georgia, are not volcanic. The Mediterranean includes the chief active volcanoes of Europe, including those of Southern Italy, Sicily, the Lipari Islands, and the Ægean Sea. Volcanoes were active also beside the western gulf of the Mediterranean, both in Spain, near Malaga, and in Morocco.

In the Indian Ocean the coasts of the mainland, like those of the Atlantic, are not volcanic, but some of the islands have been wholly, and others partly, built up by geologically recent eruptions. Madagascar has many volcanic cones, especially along its northern coasts, and the islands to the east of it—Rodriguez, Mauritius, and Réunion—are volcanoes. Réunion, four hundred miles south-east of Madagascar, is famous for the regular periodicity of its eruptions, which are said to occur every five years, while its crater contains a constantly molten lava lake. To the north-west of Madagascar the Comoro Islands are volcanic, but all those farther north between Madagascar and Asia are non-volcanic, and so is the East African coast. Recent volcanic activity has been reported from the coast of Somaliland on the basis of pebbles of a fresh hypersthene pumice, which doubtless drifted there from Krakatoa.

On the eastern side of the Indian Ocean a volcanic belt, which begins to the north at Likiang-fu in Yunnan, passes through Western Burma, the Andaman Islands and Sumatra, and then bends eastward through Java and along the southern edge of the Eastern Archipelago, where a volcano on Paloeweh, an island north of Flores, of which no previous activity has been recorded, burst into eruption in August, 1928, killed two hundred and twenty-six people, and set the vegetation on the island ablaze. One offlier from this East Indian volcanic arc occurs on the north-western coast of Australia.

Asia, with the exception of the continuation of the Burmese chain and of the north-eastern coast, contains but few recent volcanic areas. The most important are in South-Western Asia, and are an extension of the volcanic series of the Great Rift Valley in Africa; recent volcanoes occur on both sides of the Red Sea and its islands—at Aden, in Northern Palestine, and in Armenia. Where the continuation of the Rift Valley fractures break across the Caucasus a volcano has piled upon that fold-mountain chain its highest summit, Mount Elburz.

The subsidence of the Persian Gulf has produced volcanoes in Oman and Southern Persia, and there is one centre south of the Caspian. Most of the stable continent of Asia is, however, free from volcanic activity. Eruptions reported by Humboldt and other earlier travellers have not been confirmed, and the existence of active volcanoes in Asia far from the sea or from a great lake has been doubted and often denied. The evidence, however, is convincing in some cases. In addition to the records of recent volcanic activity at 80° E., 42° N., beside the Tarim Basin, numerous volcanic cones with well-preserved craters have been described from Mongolia, as by Mushketov (1881) at 43½° N., 115½° E. A little farther south Père Teilhard de Chardin found a chain of recent volcanic craters and cones. Suess has quoted the records of craters in Manchuria near the town of Mergen (48° N., 125° E.) and on the Argun River east of Lake Baikal (near 52° N., 120° E.).

The American Mongolian Expedition under R. C. Andrews discovered, one hundred and ten miles south-east of Urga (at about 46° N., 108½° E.), some recent scoria cones, sixty feet high, which proved on examination to be fused clay and due to the burning of gases at the surface. These gases are regarded by Professor Berkey and Mr. F. K. Morris as of volcanic origin (*Geol. Mongol.*, 1927, vol. ii., p. 319).

In Africa, with the exception of the Kameruns and the volcanoes already noted on the southern shore of the Mediterranean and some volcanic cones in the Central Sahara, the only recent volcanic activity is along the Great Rift Valley. There volcanic activity has been continued for a long period. The highlands of Abyssinia are capped by widespread sheets of lava, and the most valuable districts of Kenya Colony owe their fertility to their decomposed volcanic soils. The two highest of African mountains, Kilimanjaro and Kenya, are both extinct volcanoes. Kenya is the stump of a volcano in an advanced stage of decay, but the ice-filled crater of Kilimanjaro is so well preserved that it belongs to a late stage in the volcanic history of the country.

Along the eastern branch of the Rift Valley the active volcanoes include Teleki Volcano, which has occasional eruptions, at the southern end of Lake Rudolf; fumaroles and steam vents still discharge from Ol Buru, a volcano of which the main activity was Pliocene, and from the crater of Longonot, which is so well preserved that it must be of later age; and the lava on the floor of the caldron of Menengai appears only a few centuries old. Farther south Doenyo Ngai is constantly steaming and has been often in violent eruption, as from January to June, 1917. Near it are the Great Caldron Mountains of Tanganyika Territory, including one of the largest of volcanic caldrons, Ngorongoro (*cf*. p. 16). In the western branch of the Rift Valley, which includes Tanganyika and the Albert Nyanza, is the most active group of African volcanoes. They are known as the Karungu Group. They were in eruption in 1895, 1900, 1902, 1912, and later; their lavas are rich in the mineral species leucite, which is characteristic of Vesuvius.

The conclusion which has been repeatedly drawn from the occurrence of volcanoes mostly on coasts or islands is that sea-water is the cause of volcanic action. It was thought that by some means this water obtains access to subterranean molten rock, and its conversion into vapour causes the eruptions. The proximity of the ocean, however, does not necessarily produce volcanoes, for in large parts of the ocean the islands are composed of coral rock with no trace of volcanic material, and most of the coasts of the Atlantic and Indian Oceans are free from modern volcanoes. There are, moreover, well-established volcanoes far from the sea, and some of them are in arid areas where there are no large lakes. The distribution of volcanic activity appears to be determined, not by the presence of surface waters, but by the fracturing of the crust. Volcanoes occur along fractures beside sinking blocks of the earth's crust, and such sunken areas are naturally flooded from the sea or filled as lakes. The continental borders are often lines of weakness and instability, because they separate the sinking ocean floor from the upstanding land masses. The great earthquakes along the eastern and western shores of the Pacific show that those lines are undergoing earth movements, to which the volcanic eruptions are also due. The Atlantic coasts are less disturbed by earthquake action and are free from volcanoes, but along the Mediterranean and in the West Indies famous volcanoes occur where disastrous earthquakes show that the sea floors are still sinking. Iceland, standing between the North Atlantic and a basin of the Arctic Ocean known as the Norwegian Sea, is also beside an area of still-subsiding ocean floor; and volcanic eruptions have continued there till the present time, though they ceased in Scotland in the Miocene. In Australia the foundering of the Tasman Sea between New Zealand and New South Wales is doubtless partly responsible for the now extinct volcanic activity in New South Wales and for that of New Zealand; and the contemporary subsidence along Bass Strait and off the coast of Victoria was part of the movements that produced the great lava plains and well-preserved craters of Victoria.

Volcanoes are characteristic of the margins of sunken areas, whether ocean basins or sunklands. The distribution of volcanoes shows that they are formed where sinking blocks of the crust exert such heavy pressure on the plastic material below that it is forced to the surface up the fractures around the sinking areas.

CHAPTER X

VOLCANOES AND THE INTERIOR OF THE EARTH

Volcanoes and earthquakes both occur along the less stable belts in the earth's crust. These belts of weakness and instability are due to the intense heat of the earth's interior. The hotness of the water of deep springs and wells, and the heat that hampers deep mining, show that the rocks a few thousand feet deep are hotter than the ground at the surface. The rate of increase varies in different parts of the earth, from 1° F. for every twenty-two feet of descent to 1° F. for over two hundred feet. The average has been often estimated at 1° for about fifty feet and sometimes as

1° for eighty feet. It is improbable that this rate of increase is maintained within the main internal mass of the earth. It probably becomes slower, so that deep within the earth the rate is nearer 1° per mile than 1° for fifty feet. It is, however, undoubted that the interior is much hotter than the surface, and that the heat is passing, however slowly, upward into the crust and being radiated into outer space.

This cooling of the layer below the relatively cool crust is probably accompanied by the shrinkage that normally follows cooling. The internal mass of the earth may also be becoming smaller owing to the closer packing of its materials. Hence the earth consists of a hot, contracting mass surrounded by a cool and more rigid crust. As the internal mass contracts the crust must sag downward and be forced into a narrower space. The hard crust has to adapt itself to this small surface. The crust may either be wrinkled into folds, like the skin of an apple as the pulp shrinks on drying, or the crust may crack and the pieces be pushed over one another like slabs of ice blown by the wind against a shore. This contraction of the crust is proved by ample geological observations. The oldest rocks of the crust are always tilted, showing that they have been forced into a narrower space; the younger rocks are less universally disturbed; tilting in them is limited to narrow bands on the crust, forming ranges of fold-mountains, such as the Alps, the Himalaya, and the Andes. The tilting of these rocks would have been accompanied by many jerks and heavings, producing frequent and violent earthquakes; but in these intensely compressed belts of the crust there would have been no volcanic eruptions at the time of the folding.

While these fold-mountain chains were being upheaved, some parts of the earth would have sunk, and the parts relieved of side pressure would have been torn asunder by cracks like those in shrinking plaster; and huge blocks of the crust would have sunk along these cracks, and the heavy pressure on the hot rocks below would have caused this plastic material to rise up the fractures and there escape on the surface in volcanic eruptions.

Volcanic eruptions happen occasionally along fold-mountains, but they occur, not at the time of the folding, but afterwards during the resettlement of the area, as the masses come to rest. Fractures then form across the fold-mountains, and along these fractures volcanic eruptions happen, as along other fractured portions of the crust. Hence, though earthquakes and volcanoes naturally occur in the same disturbed regions of the earth, the major earthquakes are not formed in connection with volcanic eruptions, but usually at different localities. Earthquakes and volcanoes may be antidotes, for a volcano may act as a safety valve and save a district from more widespread devastation by earthquakes.

Volcanoes are useful to man in many ways. They raise from within the earth stores of indispensable materials. The carbonic acid gas discharged provides plants with their most essential food and forms limestone. Rains, streams, and vegetation are continually removing lime, phosphoric acid, and potash from the ground; volcanoes counteract this process by bringing fresh supplies of these constituents from below and raising them to a height whence wind and rivers spread them widely over the surface, where the decay of the volcanic material renews the fertility of the soil.

PART II.—EARTHQUAKES

CHAPTER I

THE NATURE OF EARTHQUAKE ACTION

THE firmness and stability of the earth are amongst its proverbial qualities. Shakespeare expressed the traditional opinion in his apostrophe " thou sure and firmset earth." The earth is perceptibly shaken every day by at least one powerful earthquake, and precise observations show that the whole surface is in a perpetual tremor. Instruments fixed by Sir George and H. Darwin at Cambridge to observe the influence of the moon were rendered useless by local vibrations; when the apparatus was set up near the southern coast, instead of doing its proper work, it recorded the changes of level due to the varying weight of water with the rise and fall of the tide in the English Channel. The classical work of d'Abbadie from 1869 to 1872 showed that his observatory, though built on solid rock four hundred yards from the Atlantic, at Hendaye—near the frontier between France and Spain—was tilted according to the height of the tide in the Bay of Biscay. Scientific observers have been frequently hampered by slight unexpected disturbances. Photographs of a star at the observatory at South Kensington were rendered misleading by the vibration due to carriages returning from a ball along Cromwell Road, nearly two hundred yards away. Some work by Sir George Airey at Greenwich Observatory on Bank Holidays was rendered impossible until long after midnight owing to the continued vibration of the ground caused by the crowds of visitors in the adjacent park. The line drawn by the earthquake recording instruments in the observatory at Calcutta, instead of being straight and sharp, is sometimes for hours a continuous zigzag owing to the tremor of the ground due to the hammering of the surf in the Bay of Bengal; and this disturbance happens even when the northern part of the bay is calm and the storm which raises the surf is five hundred miles to the south.

That the earth's crust is in a condition of constant vibration is not surprising in view of the immense speed of its movements. Any place upon the Equator is being carried by the earth's rotation on its axis at the rate of one thousand miles an hour, while the whole earth travels through space along its orbit at the rate of sixty-five thousand miles per hour, over one thousand miles per minute. As different parts of the earth's crust are of unequal strength, it is not surprising that the whole of it is quivering like a huge fly-wheel. The perpetual tremors due to the earth's movements are joined by others due to the sudden changes in temperature, unequal loads of snow and rain and tide, and the blows of the wind on cliffs and mountains. These movements are slight, but they are of essentially the same nature as a great earthquake shock that may devastate a province and cause the death of one hundred thousand people.

Earthquakes are of constant occurrence and are felt daily, even in countries as little affected by them as the British Isles. At the observatory at Eskdalemuir, in Dumfriesshire, two hundred and thirty-five earthquakes, of which sixteen were large, were recorded by the Galitzin seismograph in 1911; and it did not notice the local shocks which happen at Comrie, along the Highland Boundary Fault, in the Midland Valley of Scotland, and those at Menstrie, beside the fault along the southern front of the Ochil Hills. It did not even notice the Glasgow earthquake of December, 1910, though that was recorded by a different type of instrument at Milne's observatory, in the Isle of Wight.

The total annual number of earthquakes is estimated by Milne as about sixty thousand.

An earthquake is a wave that travels through the earth in consequence of a sudden blow or change of form. An earthquake wave is of the type known as an oscillatory wave, as the particles affected travel in a circular, or elliptical, course, and are not carried forward. Waves at sea are of two kinds. Those in the open sea are oscillatory waves, in which the particles of water move in a circular or elliptical path, and not forward, although the wave may be advancing rapidly. Along a sea beach the wave movement is disturbed by the friction of the sea bed, and the water travels forward in waves of translation. If a stone be dropped into a pool of water a wave travels out from the point of impact and gradually dies away. These waves in the open pool, like those formed by the gusts of wind striking the surface of the sea, are oscillatory waves. When the ripple reaches the edge of the pool the water may be thrown forward as a translatory wave. The apparent advance of the water in oscillatory waves is an optical delusion, as may be realized from the appearance of a field of corn when swaying under the wind; the ears appear to be travelling forward, but their movement can only be a rhythmic rise and fall, as they are anchored to the ground by the stalks.

The oscillatory waves in the earth's crust include three different types of movement. The particles move to and fro along the line of the advancing earthquake wave, so that the particles are alternately pressed closer together and then recede. They are waves of compression, or push-waves. The second movement is across the path of the earthquake wave, and, as it tends to alter the shape of the material traversed, it is known as a wave of distortion, or a shake-wave. Such waves occur in solid bodies, but not in liquids or gases. The third movements are the much larger waves which occur on the surface of the earth and are known as free waves; they throw the surface into waves which advance like those on a sheet of water. They may be so long in proportion to their height that they cannot be seen, and are then only recognized by the tilting of instruments in an observatory; but they are sometimes short, and then cause a visible wave in the ground, and throw objects upward and forward, and shake people so violently as to cause nausea as in sea-sickness.

These free waves do the damage in an earthquake. Their effect depends upon their size and speed. The length of a wave is the distance from crest to crest; the height is the vertical distance between the level of the crest and that of the bottom of the adjacent trough; the amplitude is the height of the crest or the depth of the trough, above or below the position of rest of the material, and is, therefore, half the height.

The earthquake waves travel outward from a centre which is known, from the term originally used by Aristotle, as the centrum, or centre. It is often called the "focus." The point on the earth's surface vertically above the centre, or focus, is known as the epicentre, or epifocus. The centre is usually regarded for convenience as a point, but it may be a considerable area, or a long line. The area above it is then called the epifocal area or line.

The idea that an earthquake necessarily arises at a centre—or even at a compact area—has been abandoned by E. Harboe (*Beitr. Geophysik*, vol. v., 1902, pp. 203-36); and by R. D. Oldham (*Rec. Geol. Surv. India*, Vol. 46, 1926, p. 66). They adopt the view that the focus, instead of being a point or compact area, may be a series of focal lines arranged in radial or intersecting series. The great Assam Earthquake of June 12, 1897, was very irregular, both in intensity and time, in the area of the greatest disturbance. The homoseists, instead of being arranged in a neat, concentric series, form an irregular patchwork; some areas which experienced the shock at the same time were separated by others where it was felt earlier or later.

Similarly with the isoseists; instead of the intensity steadily decreasing outward from the central disturbance, it decreased and increased irregularly. These facts are explained by assuming that the area was traversed by a system of epifocal lines, along which the shock was practically simultaneous; and places away from these lines felt the shock later than others that are close to the line but further from the centre. According to this idea the disturbance due to the earthquake was like the cracking of a pane of glass by a blow. A radial system or network of cracks is formed simultaneously; waves pass through the glass from the cracks, and thus occur in the intervening area at times which depend on distance from the nearest crack, and not from the centre of the disturbed area.

CHAPTER II

THE INVESTIGATION OF EARTHQUAKES

In the study of earthquakes the primary problem to be determined is the position of the epicentre, for when that is known it may be possible to discover the cause of the earthquake. At the epicentre the earthquake waves arise vertically from the underground centre so that the movement is simply a vertical oscillation of the ground. Water in a glass may be thrown upward and a little of it may splash over the rim, but equally in all directions. Objects on a mantelpiece may be jerked upward; pictures may be thrown off their supports and fall, but are not swung and tilted. In the area around the epicentre an earthquake movement consists of two components—one horizontal, the other vertical; and, as the earthquake advances, the horizontal component increases in proportion to the vertical. The earthquake vibration forms cracks in ordinary masonry and plaster where adjacent particles move in opposite directions at the same instant. This opposite movement often happens, for as each particle revolves around a centre, when the one particle is moving downward in one direction the next particle may be moving upward and in the opposite direction. The two particles are pulled apart, and if all the particles along a line are similarly affected a crack is produced. This crack will be at right angles to the path of the wave. If, therefore, an earthquake wave emerges at the earth's surface at an angle of forty-five degrees, the cracks formed by it in a wall of masonry will tend to be inclined forty-five degrees to the ground. Further from the epicentre the earthquake waves emerge at a lower angle and the cracks will be more nearly vertical. Hence the slope of cracks made by an earthquake indicate its angle of emergence. The directions of the cracks in buildings have been used to determine, not only the position of the epicentre, but the depth of the centrum. The results as regards depth are unsatisfactory, since, owing to the irregular structure of the earth's crust, the angles of emergence vary irregularly; and, as the waves travel on a curve instead of in a straight line, the depths were under-estimated.

The epicentre can be determined by lines showing the times at which different localities were shaken by an earthquake. A line drawn through all the places that were affected simultaneously is known as a homoseist or homoseismic line. Homoseists are usually circular or elliptical lines around the epicentre. This method is satisfactory in a country containing many accurately rated clocks, such as those along railway lines and telegraphs, but it is unreliable where the time records are dependent upon ordinary watches and clocks. In most cases more satisfactory results are given by the lines known as isoseists, which are drawn through places where the earthquake shock was of equal strength. Observations on this point can be determined after the earthquake by collecting personal experiences, records from instruments, and by observing the damage to buildings. Standards of comparison are necessary in the preparation of isoseists, and they are supplied by various earthquake scales. The scale generally used was designed by an Italian authority, Rossi, and a Genevan professor, Forel. It is therefore known as the Rossi-Forel Scale. It divides earthquakes into ten grades of intensity, as follows:

I. *Microseismic Shock:* Recorded by a single seismograph or by seismographs of the same model, but not by seismographs of the simpler kinds; the shock may be felt by an experienced observer.

II. *Extremely Feeble Shock:* Recorded by seismographs of all different kinds; felt by a small number of persons who were at rest.

III. *Very Feeble Shock:* Felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. *Feeble Shock:* Felt by persons in motion; disturbance of movable objects, doors, windows; cracking of ceilings.

V. *Shock of Moderate Intensity:* Felt by nearly everyone; disturbance of furniture, beds, etc.; ringing of some bells.

VI. *Fairly Strong Shock:* General awakening of those asleep; general ringing of bells; oscillation of chandeliers; stopping of clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. *Strong Shock:* Overthrow of movable objects, fall of plaster; ringing of church bells; general alarm, without damage to buildings.

VIII. *Very Strong Shock:* Fall of chimneys, cracks in the walls of buildings.

IX. *Extremely Strong Shock:* Partial or total destruction of some buildings.

X. *Shock of Extreme Intensity:* General disaster; buildings ruined; the ground fissured; rock-falls from mountains; extensive landslips.

This scale has to be applied with caution and common sense to allow for local conditions. The reference to bells refers to old-fashioned house bells and not to electric bells. The overthrow of chimneys refers to those of the ordinary type. In the Warnambool Earthquake of 1903 many chimneys were overthrown and the intensity appeared to be about No. VIII., whereas the other indications suggested only about No. V. The chimneys and fireplaces in this town are built of a soft dune limestone, which is used in large blocks, and, partly for strength and partly for ornament, the chimney-tops were unusually massive; the earthquake caused the chimneys to sway like an inverted pendulum, and many of them were overthrown. In such a case the collapse of the chimneys does not indicate an intensity of No. VIII.

CHAPTER III

SEISMOGRAPHS AND OTHER EARTHQUAKE RECORDING INSTRUMENTS

Early attempts to measure the direction of earthquakes were made by observation of waves in water and by the overturning of wooden cylinders. In Italy tanks with the sides above the level of the water so coloured that the splash would leave a dark mark were used to determine the direction in which the waves in the tank beat to and fro. A better device based on this principle was a tank containing mercury and with notches around the rim. The wave causes the mercury to overflow through the notches into tubes and thus record the direction of the wave. The most interesting seismograph of this type is the oldest known earthquake recording instrument. It was made in China by Choko in A.D. 136, and consisted of a copper dome with a vessel of water in the centre. It had eight outlets, each through the head of a dragon; and in the mouth of each was a round ball. Below each outlet was a bronze frog with its mouth widely open. The swaying of the instrument would throw the balls nearest in line with the path of the wave from the mouth of the dragon into that of the frog below. The approximate direction was thus indicated, and earthquakes were recognized by means of this instrument days before news arrived by messengers.

Simple seismographs, *e.g.*, those of easily overturned pillars, have been superseded by the pendulum seismograph, of which there are many forms adapted to different purposes. The kind mostly used for earthquake observations consists of a delicately poised horizontal pendulum, which, to reduce friction, records its movements by a beam of light reflected from a mirror on to a moving strip of photographic paper. The time is marked by a dot at intervals of a minute. The instrument mostly used at the present time is that invented by the Russian observer, Prince Galitzin. His seismograph is especially accurate, for, among other improvements, it avoids the swing, which renders a pendulum less responsive to the movements it is designed to record. Moreover, the record is not made by the pendulum itself, but by a galvanometer, which is connected electrically with the pendulum and magnifies the movements. This instrument has greatly advanced the interpretation of earthquake records. It enables the position of origin of a distant earthquake to be determined from one observatory alone. A seismograph record consists of three parts. When the instrument is at rest the light reflected from the mirror marks a straight line upon the photographic paper, with dots along it at intervals of a minute. The first part of the seismogram or earthquake record shows a slight oscillation of the line; in the second part the oscillation is usually two or three times as wide; the third part begins with a sudden increase of the movement till it is, perhaps, ten times as great as the second, and is sometimes so violent as to pass beyond the recording limit, and the pendulum is thrown out of action. These large movements are due to the free waves, which cause the visible heaving of the earth's surface and do all the damage. They gradually become smaller in what is known as the tail or coma of the shock, and pass into a slight oscillation that often lasts for hours before the instrument comes to rest and again marks a straight line.

The first two parts of the record are due to the preliminary tremors. The first to arrive are the waves of compression, which are the smallest and fastest of the vibrations. The second set are due to the waves of distortion. All three waves start from the earthquake centre simultaneously, and if the speed of each be known and the exact time of their arrival at the earthquake station, the distance of the origin of the earthquake can be determined. It is read from a table which is supplied with each instrument for earthquakes of different distances. As the direction of the wave is also known, the site of the earthquake can generally be at once determined.

Instruments of the Galitzin type are designed to record the earthquakes which come from a great distance. The nature of the movements which cause earthquakes may be best determined close to their origin, where they can be recorded by such instruments as the Ewing bifilar pendulum, which is hung on two threads. The instruments most used for the record of local earthquakes are known as seismometers,* and they are adjusted to record the strength and exact time of any tremor which originates within fifty or sixty miles of the instrument. Seismometers are established at various stations in an area under special observation, and if a tremor be recorded at three stations around its place of origin the centrum can be determined.

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* The Torsion seismometers that are being used to determine the nature of the existing earth movements in Southern California are described by J. A. Anderson and H. O. Wood, *Bull. Seismological Society of America*, vol. xv., 1925, pp. 1-72.

CHAPTER IV

THE CLASSIFICATION OF EARTHQUAKES

EARTHQUAKES may be arranged according to their causes, in five chief classes. First, vibrations due to surface action; second, those due to the collapse of underground material; third, volcanic explosions; fourth, widespread movements within the earth's crust; and, fifth, changes in the internal material of the earth.

In regard to the first class, tremors are produced in the earth's crust by comparatively slight causes. At Paisley, when steam hammers were used for forging, the seismograph at the Observatory could tolerate the action of one, but when two were working simultaneously the vibrations they caused overpowered any that came from earthquakes. Accordingly, landslips might be expected to produce wide-reaching earthquakes. The commonest movements of this class are slips down steep coasts where material is continuously being added to slopes already at the angle of repose. Such slips are best known from their effect on telegraph cables. A cable is suddenly broken, and when the part is raised it is found twisted into elaborate Gordian knots, as it has been pushed down the slope by the sliding earth. The time of such accidents has been accurately known, but none of them have been certainly observed on any seismograph, so that the vibrations they produce apparently do not affect the solid crust.

Great landslips may strike a much heavier blow. In 1911 a huge landslip at Uroi in Turkestan blocked up a valley and formed a large lake; an earthquake of first-rate severity was recorded at the time by the Observatory at Pulkova, near Leningrad, and was attributed to the landslip; but restudy of the evidence by Oldham (*Quart. Journ. Geol. Soc.*, vol. 79, 1923, pp. 243-244) showed that the landslip was not at the epicentre and was an effect of the earthquake and not its cause. This conclusion is supported by the fact that the disastrous landslip at Frank in Alberta on April 29, 1903, produced no recorded earthquake. Part of Turtle Mountain had been left unsupported by coal-mining, and a mass two thousand eight hundred feet by one thousand one hundred feet wide and one thousand seven hundred feet thick, weighing two hundred and fifty million tons, fell two thousand feet upon the town of Frank. The noise and the column of dust which rose from the place gave rise to the report that a volcano had burst into eruption; but no vibration due to this mighty crash was recorded by any seismograph.

Another constant source of tremors are variations of the load on the crust, by changes in the pressure of the air, in the weight of water with the rise and fall of the tide, and by the fall of rain and snow. Such influences cause depressions of the crust, which are followed by an uprise and by recognizable tilting of earthquake recording instruments.

The second class—due, for example, to rock-falls within the crust, have more serious effects. The most likely areas for such movements are near dying or recently extinct volcanoes. The discharge of the lavas must leave spaces underground, while the contraction of rocks on cooling after the cessation of volcanic activity would produce open spaces and occasion the fall of material and a jar on the surface like the "creep" that occurs on the collapse of the roof of an abandoned coal-mine. Such shocks on the surface may be disastrous but local in their range. The Island of Ischia, off the Italian coast near Naples, is of volcanic origin; the chief crater, Epomeo, became extinct in prehistoric times, but later eruptions have happened on its flanks. The last of the main series was in A.D. 305, and after an interval of almost one thousand years the final eruption was in the year 1302. Casamicciola, the chief town of the island, was seriously damaged by an earthquake in 1881; the town was rebuilt, and on July 28, 1883, a still more severe earthquake destroyed most of the houses and killed two thousand three hundred and thirteen of the inhabitants. Both earthquakes were carefully investigated by H. J. Johnston-Lavis, and he showed that the area most seriously affected was a narrow band radial from the crater of Epomeo. He calculated the origins of both earthquakes, from the angle of emergence of the shock, at about one-third of a mile. According to Mercali, the depth was three-quarters of a mile. The movement at Casamicciola was almost vertical; it was shaken to pieces by blows from below which made things jump into the air.

These Ischian earthquakes have received two different explanations. According to Johnston-Lavis, fresh lava rose along one of the old volcanic fissures, and he regarded the earthquakes as a warning that another eruption was probable. It has not happened, though nearly fifty years have passed. According to the alternative view, the earthquakes were due to the volcanic activity of Ischia having become extinct, as in Rome and Tuscany; the temperature of the ground is therefore falling, and the shrinkage of the rocks has led to collapse of subterranean spaces or to faults along the old fissures. On either theory the cause was local and was in the root of the old volcano at a comparatively shallow depth. Its shallow origin is probable, since, although the destruction was absolute at Casamicciola, the earthquake was barely noticed at Naples, twenty miles away, and was not recorded by the instruments at the Vesuvius Observatory twenty-eight miles distant.

The third class of earthquakes is due to volcanic eruptions. They are accompanied by many slight earthquake shocks which affect only a small area. But great volcanic explosions like those at Krakatoa and Mount Pelée produce waves that spread worldwide.

The fourth class includes the majority of the major earthquakes; they are known as tectonic, because they are due to movements of great blocks within the crust of the earth. Most earthquakes are formed along deep-seated faults. The earthquake-forming movements along these faults may be either vertical or horizontal. Vertical movements cause an uplift of the land, or a subsidence, or both. Earthquake uplifts have been doubted, but have been proved in many places, as in New Zealand and along the coast of Chile in 1822, as described by Darwin. The irregular tilting of a wide tract of country was caused by the earthquake of June 16, 1819, in Cutch; the country to the north was uplifted twenty feet, while to the south the land sank ten feet. In the Assam Earthquake of 1896 some of the valleys were warped with an uplift in some places and a downward movement in others. The horizontal movements of the ground have been often shown in New Zealand by a fence being cut across and the two ends displaced by several feet. The same effect was observed after the Californian Earthquake in 1906. A well-known vertical fault was formed by an earthquake at the Mino-Owari Earthquake in Japan in 1891, when a cliff twenty feet high was formed across a road. The horizontal displacement of objects which are thrown forward by the earthquake wave often has disastrous results. Thus a wave travelling along a railway line pushes the rails forward and buckles and twists them into serpentine curves, and bridges collapse by the girders riding forward off the piers.

The close connection of earthquakes and faults is well illustrated in the British Isles. The severest earthquakes in Scotland have been those at Inverness, due to the fault which passes along Loch Ness and the valley of the Caledonian Canal. The most numerous of the minor British earthquakes happen at the Highland Boundary Fault, which forms the northern margin of the Midland Valley of Scotland; frequent slight slips along this fault produce the numerous earthquakes at Comrie. Similar movements along the fault that has formed the southern front of the Ochil Hills give rise to the many slight earthquake shocks at the village of Menstrie.

The Glasgow Earthquake of December 14, 1910, which reached an intensity of about 5·5 on the Rossi-Forel Scale, was doubtless due to the subsidence of a strip of land between two faults running east and west in the northern suburbs of Glasgow.* Earthquakes often happened along hidden faults. Thus the most severe of modern British earthquakes, that of Colchester in April, 1884 (intensity 8·5), is attributed to movement along a fault in the deeply buried foundation of the country.

Great faults are still being formed by submarine earthquakes. Thus the movements that broke up the old land around Greece and between it and Asia Minor are apparently still going on; for in October, 1873, an earthquake west of Greece lowered part of the sea floor, leaving a cliff six hundred feet high. Three years later an earthquake near Crete broke the cable in two places, and the bottom was made so irregular that the cable had to be relaid on a new route. In 1886 a cable from Zante to Crete was broken and the depth of the sea reported to have increased by one thousand three hundred feet. The earthquake which overthrew a large part of the city of Corinth in 1928 was due to movements of the same series and along one of the series of faults that has made, and is probably still enlarging, the Gulf of Corinth.

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* The fullest statement of facts regarding this earthquake is in the *Trans. Geol. Soc.*, Glasgow, vol. xiv., 1911, pp. 89-114.

The earthquakes due to submarine faults include the Lisbon Earthquake, which is historically the most famous owing to its great loss of life and to various fictions which have grown up regarding this tragedy. It happened on November 1, 1755, when at 9.40 a.m. Lisbon was startled by a noise as of thunder; a violent shock, according to Lyell, in six minutes killed sixty thousand people and rent the mountains of Portugal by fissures, up which came flames and smoke. According to Humboldt, the area shaken simultaneously was four times the size of Europe, extending from the West Indies to Eastern Germany and from Sweden and Scotland to Morocco, where a " village " with ten thousand inhabitants was swallowed up by the opening and closing of a fissure. A similar engulfment is said to have buried the victims at Lisbon.

This earthquake well illustrates those secondary effects which are often the most disastrous. Lisbon is built partly on limestone hills, and the buildings on them with a solid foundation suffered no serious damage. Churches with elaborate sculptured ornaments were not injured, and there was apparently no loss of life. The lower part of the town stands on a low alluvial plain between the hills and the Tagus, and there the earthquake wrought havoc. The people fled from the narrow streets on to the great stone mole or quay beside the river. While the people were collected there for safety, it was noticed that the water receded and the front of the quay was left bare. This recession was due to the ordinary lowering of the surface before an advancing wave, which consists of water drawn in from the front as well as from behind. The earthquake wave swept in from the sea and struck the mole; it collapsed, and all the people on it were swept away and drowned. The reported figure of sixty to seventy thousand is improbable, since, as the population of Lisbon in 1806 was two hundred thousand, in

1755 it was probably much less.* The fact that no bodies were found afterwards also suggests doubt as to the number drowned. According to tradition, the quay was swallowed up by an unfathomable abyss which engulfed all the victims. The Tagus is comparatively shallow, and no trace has been found of this reported abyss. The disaster was probably due to the mole being too heavy for its foundation, and, being weakened by drainage of mud from underneath during the recession of the water, was shattered and slid down the bank when struck by the wave. The contemporary accounts give no mention of the abyss, and they report no damage in the higher part of the city.

The range affected by the Lisbon Earthquake has also been greatly exaggerated from the belief that it was felt by some miners in Derbyshire and caused a wave on Loch Lomond. The earthquake in Lisbon occurred at 9.40 a.m., which would have been 9.24 at Loch Lomond, where at 9.30 a wave was formed which passed up and down the loch. A wave was produced at Loch Ness, near Inverness, a little before 10 a.m. The earthquake was felt all across Portugal and Northern Spain to the Pyrenees and in the extreme south-west of France; but it was not recorded from the neighbourhood of Bordeaux, or from Northern France, or from the south of England, except for an earthquake wave which reached Portsmouth at 10.35, the Thames and the east of London at 11, and Yarmouth at noon. A wave was also recorded, though very belated, in Western Cornwall at 2 p.m., and at Swansea between 6 and 7 p.m. The shock felt in the lead mines in Derbyshire was at 11 a.m., and was obviously due to one of those independent shocks which occur in many parts of the world at the time of a major earthquake. The disturbances in Scotland were probably also due to an independent shock which happened a few minutes before that at Lisbon. The earthquake appears to have been due to some earth movement under the Atlantic to the west of Portugal. Various ships in that region were violently shaken, and the waves from it struck the coast of Portugal and subsequently reached the English Channel and travelled across the Atlantic to the West Indies.

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* R. Twiss, *Travels Through Portugal and Spain in* 1772 *and* 1773 (1775), p. 26, remarks: "It is very difficult to ascertain the number of inhabitants in Lisbon." He quotes a French estimate of 1730 as two hundred and fifty thousand; of Antonio Freire in 1739 of eight hundred thousand; and of an attestation sent to Rome in 1754, to secure Bulls from the Pope, as six hundred thousand! According to Twiss, the earthquake "is said by some to have destroyed fifteen thousand persons, by others twenty-four thousand, and by others seventy thousand." The loss, he remarks, "however great, is at present not sensibly perceived." The probable population of Lisbon in 1755 renders the death-roll of seventy thousand highly improbable.

The great Assam Earthquake of June 12, 1897, was far more powerful than that of Lisbon. It had a wider range and was more destructive. It was carefully investigated and described in a monograph by Dr. R. D. Oldham (*Mem. Geol. Surv. India*, XXIX., 1899). This shock completely devastated one hundred and fifty thousand square miles of North-Eastern India, and it was felt throughout four million two hundred thousand square miles. Within the former area all buildings, railways, and bridges were completely destroyed; the earthquake rent the hills; the plains were fissured; floods of sand and water were ejected through earthquake craters, and landslips ruined much valuable land. Faults raised cliffs up to thirty-five feet in height. The level of the land was raised in some places and lowered in others, and lakes formed in the hollows. Owing to alterations in the surface level, the whole of the Bramaputra River was visible from a point whence previously only part of the river had been seen. The shock lasted for two and a half minutes, but the destruction was done in the first few seconds. It was inevitably complete, for the ground, according to Oldham, moved backward and forward for a range of fourteen inches, and in places of eighteen inches, two hundred times a minute. No masonry could withstand such treatment. Walls were completely shattered, while trees were snapped across a couple of feet from the ground, as the upper part could not keep pace with this violent oscillation of the base. The land was described by many observers as thrown into waves like a choppy sea. These visible waves, according to Oldham, were about thirty feet long and one foot high, and when they were passing people found it difficult to stand. The ground was fissured where adjacent particles moved in opposite directions at the same time, and along the fissures were built up ring-shaped mounds of sand, known as earthquake-craters. They have been regarded as supporting the connection between earthquakes and volcanoes, but they are in no way volcanic. They occur where a stiff layer of compact earth lies upon a soft, water-logged layer, which in turn rests upon the underlying rock. The earthquake caused the rock surface to strike the water-logged sand terrific blows two hundred times a minute; each blow forced a jet of sand and water out through any crack in the overlying layer. When the rock was lowered it tended to create a vacuum in the bed above it, and sand, water, and air would be sucked downward, to be driven up again on the reverse movement. Accordingly, a column of sand-charged water was kept sharply rising and falling in the fissure, wearing the softer places along it into circular pipes. Some of the sand thrown out at each upward movement would accumulate around the mouth to form the ring-shaped mound or crater.

The vibration of the surface causes the earthquake sound, which in Assam was a roar like thunder. This noise is due to the vibrating ground beating upon the air like the membrane of a drum. The vertical up-jerking of the surface was so powerful that heavy stone pillars were shot out of the ground without damaging their sockets, so that they were thrown upward at an angle of over sixty degrees. The shock damaged many buildings in Calcutta two hundred and fifty-five miles away, and reached Europe in waves thirty-five miles long, with a rise and fall of twenty inches. The first tremors, the waves of compression, reached Europe at the rate of five and a half miles a second, while the main free waves followed at two miles per second.

The earthquake with the highest death-roll and most costly devastation happened in South-Eastern Japan on September 1, 1923. It was doubtless the most disastrous earthquake that the world has ever known. Never before has an earthquake of such power had its focus so near to a great centre of population. The cause of this calamity was a violent dislocation of the floor of Sagami Bay, sixty-five miles to the south of Tokyo, the capital of Japan, and eighteen miles from Yokohama, its chief naval port. The floor of the bay in one place sank three hundred feet, and close by was upheaved six hundred feet. On the shore of the bay the land was in places raised and at others lowered. At Misaki, on the end of the Muira Peninsula, the ground was uplifted twenty-five feet, and part of the adjacent sea-bed was raised above sea-level; but three days later the ground began to sink at the rate of about two feet a day, until it came to rest six feet above the original level.

The shock due to these earth movements travelled northward to Tokyo. Yokohama, being only eighteen miles from the centre, received a shock of the utmost severity. Motor-cars in the streets were thrown into the air and fell upside down. Houses and a hospital on the edge of "the Bluff" were hurled northward over the cliff. At Tokyo, which was reached by the shock one minute sixteen seconds before noon, it was less severe. It was felt unequally, the higher parts of the city being less affected than the lower parts that were situated on water-logged alluvial ground. The uplift of the observatory by the earthquake wave was less than half an inch. In the main street shop windows were smashed; the proprietors swept up the fragments and were prepared to continue business. But, unluckily, all through Tokyo the midday meal was being prepared, and many of the charcoal braziers were overthrown, strips of paper and laths of wood fell on to the floor and were set alight, and fires broke out simultaneously in different parts of the city. The water mains were broken, so the fire brigade was powerless, and Tokyo was swept by an irresistible conflagration. The people fled to the bridges and open spaces and were there suffocated by the tens of thousands. The total loss of life was one hundred and forty-two thousand eight hundred and seven, and the property destroyed is estimated at £950,000,000 by the fire and £50,000,000 by the shock. On the higher parts of Tokyo the direct injury to buildings was slight. In the areas most affected modern strongly built edifices such as the tall "sky-scrapers" were uninjured, and light ornamental structures on their roofs showed no signs of having been seriously shaken. As in many cases, the secondary effects at Tokyo were far more disastrous than the actual earthquake.

CHAPTER V

THE GEOGRAPHICAL DISTRIBUTION OF EARTHQUAKES

EARTHQUAKES, like volcanoes, occur mostly along the belts on the earth which have undergone great recent geographical changes. In the Old World, the major earthquake region is along the Alpine-Himalayan systems from the Western Mediterranean across South-central Asia, including Asia Minor, Persia, the Himalaya, and China. South-western Europe and Northern Africa are affected by an earthquake belt in the Eastern Atlantic, past Spain, to the Cape Verde Islands. The most active African belt is down the eastern side of the continent from the Great Rift Valley on the west to Madagascar and the band off the East African coast. Eastern Asia is bordered by the band from Kamschatka through Japan to the Philippines, which is notorious for the prevalence of serious earthquakes in Japan. Another band extends from Siam and Indo-China along the East Indian archipelago to New Zealand and along that oft earthquake-shaken land. The last great eastern belt is along the western coast of America from Alaska to Patagonia, with a branch eastward which includes the West Indies and joins the East Atlantic area off Portugal and North Africa.

Earthquakes, therefore, like volcanoes, often occur along the continental margins, but the connection with coasts is incidental to joint independence on recent earth fractures. Thus the western coasts of America are notorious for the numerous earthquakes of supreme violence, whereas the Atlantic side is relatively free, except in the West Indies and for the occasional severe earthquakes on the coastline from Charleston to the St. Lawrence. The contrast between the frequency of earthquakes on the Pacific and Atlantic coasts of North America is shown by a list of those recorded from 1915 to the end of 1923. California had five hundred and ninety-four; second on the list was another Pacific state, Washington, with thirty-seven; on the Atlantic coast, New Jersey had two each, Vermont and Maryland one each.

Earthquakes show that the existing main lines of instability on the earth's crust are along the western mountains of America, along the Mediterranean and the Himalayan Mountain system, and in the East Indies, and the festoons of islands in the Western

Pacific; and they are all areas of great recent movements on the earth's crust.

The movements are mainly due to subsidence and uplift, but some are apparently caused by the lateral movements of blocks of the crust. The evidence for these horizontal movements is strongest in California, where successive surveys since 1854 have discovered differences in the position of some of the signal stations greater than should be due to errors in the work, for they amount in places to twenty-four feet. As the observations indicated that some places were moving northward and others southward they were at first discredited; but it seems probable that the blocks are moving in opposite directions. If a mosaic be squeezed so strongly that the pieces shift their places the advance of one piece may force those beside it in the opposite direction. The earth blocks in the Coast Ranges of California appear to be slipping against one another. According to Professor Bailey Willis* for one hundred miles south of San Francisco the earth blocks are moving southward, while those further south are moving northward. The result is frequent earthquakes, such as that which devastated Santa Barbara, a coast town west-north-west of Los Angeles, on June 29, 1925.

CHAPTER VI

THE DEPTH OF ORIGIN OF EARTHQUAKES

THE depth at which earthquakes start has been a matter of long controversy. The first serious attempt to determine this depth was by Mallet in his study of the Neapolitan Earthquake of 1857. From the angle of emergence Mallet concluded that this earthquake had started from a depth of about six and a half miles. A more precise method—the intensity-curve—was applied by Dutton to the Charleston Earthquake of 1886. As an earthquake wave travels outward it becomes less powerful, and Dutton held that the distance from the epicentre of the decline in strength is proportional to the depth of the centre. Thus, if an earthquake at a distance of one thousand miles from the epicentre has an intensity on the Rossi-Forel Scale of IV. to V., if it were generated at the depth of one hundred miles, its intensity at the epicentre would be No. VII. but Dutton held that in all known cases such an earthquake has an intensity at the epicentre of No. X. He claimed from this principle that, as the Charleston Earthquake had an intensity of No. IV. at four hundred and fifty miles, and of No. III. at six hundred miles, its depth of origin was about twelve miles; and that as the Ischian Earthquake of 1883 had an intensity twenty-two miles away of only III. and of X. at the epicentre, it must have been formed at one-twelfth of the depth of the Charleston Earthquake, or half a mile. Milne objected to this method, as it assumes that the shock starts from a point, whereas if it originated along a line the results would be very different; the loss of intensity, instead of being inversely as the distance, would then be inversely as the distance cubed. Milne nevertheless concluded that earthquakes do not arise at depths of more than about twenty miles. Stukeley had estimated in 1750 that as the earthquake in Asia Minor in A.D. 17 overthrew thirteen cities and devastated an area three hundred miles in diameter, it must have its origin two hundred miles deep.

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* Bailey Willis, *Bull. Seism. Soc. Amer.*, vol. xv., 1925, pp. 275-276.

This idea is supported by the comparative depths of two earthquakes during 1925 in California. On July 19 and August 21 areas of about the same size were shaken; in the first the intensity at the centre was only about III. of the Rossi-Forel scale, and its depth was calculated at eighteen miles; the second had an intensity at the centre of VI., and its depth was calculated at seven and a half miles.

Stukeley's conclusion was a common-sense realization of facts which have been established by the records of the best modern seismographs. In the Assam Earthquake of June 12, 1897, places ninety miles apart felt the shock within two seconds of time, although the earthquake wave would not have travelled at more than three miles per second. The time interval that would have been expected would have been perhaps thirty seconds instead of two.* Oldham could only explain these facts, if the earthquake arose within a few miles of the surface, by the assumption that the whole area had been pushed forward on a thrust plane, at the depth of about five miles. On re-estimating the depth in 1926 he concluded that if the earthquake had started on a line fifty miles long, its focus would have been one hundred and fifty miles deep, whereas if it started from a centre it must have been at the depth of one hundred and ninety miles. L. Pilgrim, of Stuttgart, 1913, had, on similar grounds, placed the focus of the Guatemala Earthquake of April 18, 1902 (*cf.* p. 32) at the depth of one hundred and five miles, and of the Calabrian Earthquakes of September 8, 1905, and October 23, 1907, and of the Californian Earthquake of April 18, 1906, at the depth of ninety miles. Still greater depths have been adopted in later times by many leading authorities.† G. W. Walker, the late head of the observatory at Eskdalemuir, concluded, from the angle of emergence of many world-shaking earthquakes at Pulkova, near Leningrad, that they started at the depth of eight hundred miles. Professor H. H. Turner, from the time of arrival of an earthquake at two antipodal points on the earth's surface, concluded that some earthquakes arise at the depth of forty miles, the majority at the depth of about one hundred and twenty-five miles, and some at the depth of three hundred and seventy-five miles. This view has been adopted recently by K. Wadati, of Japan, who attributes the earthquake of July 26, 1926—under the Yellow Sea—to a depth of two hundred and fifteen miles.

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* R. D. Oldham, *Mem. Geol. Surv. India,* xlvi., 1926, pp. 59-60.

† The great depth of earthquake origins is not accepted by all authorities. Thus S. K. Banerji (*Phil. Mag.,* January, 1925) believes that they are formed within eight miles of the surface. Perry Byerly (*Bull. Seis. Soc. Amer.,* vol. xv., 1925, p. 152) adopts the attitude that the evidence is so uncertain "that we

That earthquakes arise from great depths is also indicated by their distribution in time. They tend to recur at regular intervals. In some places they are more often noticed in the winter than the summer, and were attributed to the variations of atmospheric pressure with boisterous winter storms. The period was determined by Professor H. H. Turner in 1912 as of the length of four hundred and fifty-two days. It is, therefore, not annual, and cannot be seasonal, or due to tides or weather. The period agrees with Chandler's "preccessional mutation," and shows that the major earthquakes are due to some process acting deep within the earth (*cf*. G. W. Walker, *Modern Seismology*, 1913, p. 88; and Milne, *Earthquakes*, sixth edit., 1913, p. 377).

Shallow-seated earthquakes appear to be seasonal. Many authorities, from Merian (1834) and Perrey (1841-43) to Knott, have claimed that earthquakes are most numerous in winter—as they are in Scotland—when the surface is affected by sudden changes in air pressure during boisterous weather. Omori, in 1899, showed that in Japan they are most frequent in

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are able to draw no definite conclusions as to possible depths of focus."

some areas in winter, and in other areas in summer. The major earthquakes being deep-seated in origin appear quite independent of the seasons.

CHAPTER VII

EARTHQUAKES AND THE INNER STRUCTURE OF THE EARTH

THE study of earthquakes owes part of its importance to the light it throws on the internal structure of the earth, upon which it is the most instructive source of information. This work was begun by John Milne, who noticed, when collecting information as to the time of arrival of earthquakes at different localities, that, beyond a certain distance, they arrived earlier than was expected. They would save a little time by travelling in a straight line through the earth instead of passing around the curve on the surface; but the increase in speed was greater than could be thus explained. Milne found that if the earthquake on its course passed to a greater depth than forty or forty-five miles, its speed was greatly increased. This fact was proved from many parts of the earth. Milne, therefore, concluded that below the depth of about forty-five miles the earth consists of material that transmits earthquake waves much faster than the rocks of the crust. He concluded that the material would be nickel-iron, like that which forms the iron meteorites. Milne called this material geïte, as it is the rock which forms the great bulk of the earth. This conclusion is supported by the weight of the earth as a whole, and by the evidence of radio-activity.

This line of work has led to the most suggestive information at present available regarding the internal structure of the earth. To understand the problem it is necessary to remember that earthquake waves are due to two kinds of vibration. In one kind the particles move to and fro along a straight line so that the particles are alternately nearer together and farther apart. This type of vibration forms waves of compression or condensation, like waves of sound in the air; as the vibration is along the path of the wave it is longitudinal. The waves thus formed in connection with earthquakes are known as the primary or P waves, for which Professor Turner has suggested the appropriate name of Push-waves.

The second kind of vibration is sideways, across the path of the wave. It produces the S, or secondary, waves, which tend to alter the shape of the material they pass through. They are distortional waves, or, according to Professor Turner's term, Shake-waves. It was shown by R. D. Oldham in 1900 that the waves travel through the earth at different speeds, and that the push-waves arrive before the shake-waves, as remarked previously (p. 56). It was noticed during the study of a Croatian earthquake by A. Mohorovicic that at distances of more than six hundred miles from the origin two push-waves and two shake-waves were recorded, and that the slower waves were the larger. These double sets of waves were both explained by the slow high waves travelling direct through the upper part of the crust; the waves that had travelled at a greater depth passed through material that transmitted them faster than at the surface. The faster waves, therefore, at distances of somewhat over six hundred miles, arrived first, although they had had a longer way to go.

Mohorovicic explained the course of these waves as due to their striking a denser layer in the earth and being reflected from it to the outer surface. He described this reflecting surface as a "surface of discontinuity" between two types of material. The slow waves were the only ones felt near the place of origin of the earthquake; further away the fast waves are felt, and felt first; and further away only the fast waves are observed, as the others have died away.

The surface of discontinuity was estimated at a depth of about forty miles, and it separates the rock of the earth's crust from some more elastic layer. In the outer rock layer the push-waves travel five miles a second, and the shake-waves two and three-quarter miles per second. Hence, under the rocky crust or lithosphere of the earth, about forty miles thick, lies a much thicker shell of a more elastic material; this shell is estimated at about one thousand eight hundred miles thick, and in it both push and shake-waves go much faster than in the rocky crust. This layer is the barysphere, and consists mainly of the rigid nickel-iron mass of the earth. It is divided into various sub-shells, as the proportions of earthy constituents diminishes and the amount of metallic iron and nickel increases. In the outer seven hundred miles of the barysphere the push-waves go seven and three-quarters and the shake-waves four and a quarter miles per second. Below the depth of seven hundred and forty miles, for another four hundred miles, these rates increase to eight and a quarter and four and a half miles per second, and the speeds continue to rise till, at the depth of about one thousand five hundred miles, they reach the maximum of eight and a half miles per second for the push-waves and 4.7 for the shake-waves. Then for about three hundred miles the speed decreases slowly to about eight and a quarter and four and a half miles per second. Then follows a startling change; the push-waves suddenly drop in speed to five and a quarter miles per second, and the shake-waves are stopped altogether. At the depth of about one thousand eight hundred miles is the relatively sharp passage from the barysphere to the centrosphere, or core of the earth, which must be about four thousand two hundred miles in diameter.

The fact that the core is impervious to shake-waves indicates that it must be composed of liquid material.

Push-waves can pass through solid, liquid, and gas, whereas shake-waves can only pass through solids. Oldham suggested that the core of the earth, which he considered about three thousand miles in diameter, might be composed either of material so rigid and dense that it resisted the entrance of the earthquake waves, so that the area behind it was in "earthquake shadow"; or else that the core consists of liquid or gas. Further work has led to the general conclusion that the central core below the depth of about one thousand eight hundred miles and about two hundred miles in diameter, consists of a liquid, since it does not transmit the distortional or shake-waves.*

Hence, according to the evidence of earthquake waves, the earth consists of a central core or "centrosphere" of some liquid, probably molten iron, containing nickel and other metals; this core is surrounded by a shell of solid, compressed, metallic iron, which passes upward through mixed metal and rock to the outer layer of the rocky crust. The ordinary rocky crust or lithosphere is about forty miles thick.

CHAPTER VIII

PRACTICAL RESULTS OF EARTHQUAKE STUDY

THE practical application of earthquake studies aims at the mitigation of their mischief by warning of their likely occurrence and construction of buildings that best resist destruction. The prevention of earthquakes is outside the range of human possibility, but they could be rendered far less disastrous if their occurrence was foreseen, for precautions could be taken to prevent panic and fire and the secondary disasters that are often the most calamitous. The possibility of foreseeing earthquakes is encouraged by the fact that they are due to the gradual increase of strain in the rocks by some movement, as along a fault. The rock is under strain like a spring. When the strain reaches the breaking point, the rock yields in a sudden snap and springs into a position of relief. Many earthquakes are attributed to this "elastic rebound" when the strain is removed.

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* Some authorities, such as Gutenberg and Macelwane, consider that they have detected shake-waves which have passed through the central core, but the liquid nature of the core, as advocated—*e.g.*, by Knott—is now generally accepted.

During the development of this strain there may be a slow tilting of the ground, or the rocks may experience slight slips which may increase in number and strength. Recognition of these processes might indicate the advent of an earthquake and its probable date.

The statistics of earthquakes show that they are to some extent periodic. It has been claimed that they are more numerous in winter than in summer, as the changes of the weather are then more boisterous, and atmospheric pressure on the earth's crust is liable to greater and more sudden variations. The Tokyo Earthquake of September 1, 1923, happened at the passage of a cyclone with an unusually low air pressure, which may have precipitated an earthquake due to slowly accumulating strain in the crust.

The study of earthquakes gives useful guidance as to sites liable to injury. Geology reveals the lines of dislocation in the crust, and shows positions which are liable to sudden earth movements. It also indicates positions along a coast that are liable to be swept by earthquake waves, as at the heads of tapering bays which are widely open to the sea and have a gradually shelving floor.

The most practical help that may be expected from seismology is in the design of buildings to withstand earthquake shocks and in the selection of suitable foundations. That loose earth would absorb the shock and therefore afford a safer foundation than a hard rock has often been suggested. The Temple of Diana at Ephesus is said to have been built on a swamp as a protection against earthquakes. Some of the earthquakes in Southern Italy have done more damage in rocky country than on the alluvial plains, but that effect may have been because most of the towns and villages were on the hillsides and comparatively few on level ground. It is true that the tremor due to an explosion or the fall of a heavy weight travels farther through a firm rock than through loose earth; but the surface waves, which are the destructive agent, are higher in loose than in compact material. Hence a deep trench around a house, and especially on the side from which the earthquake waves come, may be an effective protection, as it saves the site from the free waves. The Greek temples were built of a comparatively light superstructure on a massive platform of masonry. The platform on a swampy ground will behave like a pontoon and rock as a whole, and thus allow the waves to pass without overthrowing the temple.

Many attempts have been made to use loose foundations in modern construction. R. Stevenson designed for Japan a lighthouse built on a layer of cannon balls, in the hope that the play between the balls would reduce the rocking by earthquake waves which splashed the oil out of the lamps. The lighthouse was not a success, as it suffered more from wind than its predecessor had done from earthquake. J. Milne employed this method to secure a room that would be stable during earthquake shocks. The room was first placed on a platform of cannon balls, without success, but when the cannon balls were replaced by iron shot a quarter of an inch in diameter the plan answered, for there was sufficient friction between the shot to avoid movement by the wind, while the structure remained still during strong earthquakes. For ordinary purposes it is found that a firm and deep foundation is by far the safest, for, though the vibration is rapid, the waves are low. A building resting on a deep foundation is less affected by the surface waves, just as a ship of deep draught is less tossed by the waves than a shallow craft.

In anti-earthquake design two main lines have been tried. The building has been made light and elastic, so that it yielded to shaking like a basket without being knocked to pieces. Houses built on that plan were indestructible by earthquake, but they proved uncomfortable, as their plaster ceilings and walls were readily cracked, and a slight shock produced alarming dust and creaking. The alternative plan is to tie all parts of the building so firmly together that it is as rigid as a box. The fullest development of this system is in constructions of reinforced concrete. Buildings on this plan have resisted calamitous earthquakes most successfully. The building should be so designed that the whole of it vibrates together. If a building and its wings differ in height or direction, they will vibrate at different rates and thus tend to be torn apart.

Some Japanese temples consist of a platform or sole-plate which bears vertical pillars that are well tied by cross-beams and firmly attached to the roof. Such buildings move together as a unit and are practically earthquake proof. The modern American skyscrapers are so heavy that their deep foundations pass below the level of the main free surface wave, and the buildings have to be so strong to resist the wind pressure that they are safe from any earthquake, unless they should be close to the epicentre of one of the highest force.

The building material which in ordinary conditions best withstands earthquake is a steel framework with walls of reinforced concrete; a steel frame with brick walls is more liable to damage, as the bricks are crushed when the frame is distorted, whereas the concrete yields and is more elastic. A reinforced concrete frame and brick walls is still weaker, and a brick building without a framework is still less resistant. Buildings of clay, especially if they have a heavy roof, are shaken to pieces by moderate shocks.

Buildings are often injured by the overthrow of the chimneys, which are especially unstable if built with a heavy top, for they then sway like an inverted pendulum and may crack the walls or collapse and smash the roof.

The safety of buildings is being increased by improvements in architectural design. Windows are a source of weakness, as cracks run from one to another and they act like the perforations in a sheet of postage stamps. This danger can be reduced by better spacing. The arch, unless buried underground, is unsuited for earthquake-stricken areas, as when the two sides move in opposite directions at the same time the crown is apt to be torn asunder. Building design is being guided by the Californian experiments organized by Professor Bailey Willis. Different structures and models are subjected to the vibration similar to that of a powerful earthquake on a miner's shaking-table, which is used to separate ores from their matrix. These tests show the materials and constructions that best resist the type of earthquake to which the locality is most liable.

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FUEL

ITS ORIGIN AND USE

By

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LONDON: ERNEST BENN LIMITED
BOUVERIE HOUSE, FLEET ST. E.C.

First published 1929

MADE AND PRINTED IN GREAT BRITAIN BY
BILLING AND SONS, LTD., GUILDFORD AND ESHER

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FUEL: ITS ORIGIN AND USE

CHAPTER I

INTRODUCTION

FUEL, the dictionaries tell us, is "anything that feeds a fire," and is a corruption of the old French word *fouaille,* derived from the Low Latin *foallia,* fuel. And what is fire? The old idea was that heat was an emission—a subtle imponderable fluid, but the theory now accepted by physicists is that it is a condition of matter, due to the vibratory motion of the molecules of which the matter in question is constituted. The hotter the body, the greater the velocity of the particles. It is necessary for the validity of this theory that we accept the existence of ether, an elastic imponderable something "which pervades all matter and infinite space," otherwise the heat of the sun could not reach the Earth, ether being necessary in order that the vibrations of the sun matter may be communicated to the matter of the earth. It is possible for one substance in a state of vibration to communicate vibrations to another substance—that is, increase its temperature. When one substance is rubbed against another, heat is produced by friction, and it is demonstrable that the heat produced is the measure of the motion destroyed—an exemplification of that great and standing marvel, the conservation of energy. Vibration of molecules may be set up by chemical combinations. Sometimes the heat is small, the process being slow, as in the case of the oxidation of iron to form rust. Sometimes the heat is great and the process rapid, as when the carbon and hydrocarbons of a piece of wood are caused to combine with the oxygen of the air, a feature which is known as combustion. Some combustible substances burn with flame and some do not. When a substance burns with flame it shows that gas or vapour is being evolved, for a flame cannot exist without there being a gaseous or vaporised substance, a flame being such a substance raised to a high temperature of combustion. There is an intimate connection between heat and light; the illuminating quality of a flame is due to the presence of solid matter in the flame, and thus in the flame of a candle or lamp certain gases are decomposed with the production of solid carbon, which becomes incandescent in the flame. The heat does not depend upon the illuminating quality of the flame; the hottest flame is that of hydrogen, which is the palest of flames. It is possible to set up incandescence without burning—that is, without chemical decomposition—by passing a current of electricity through some electrical-resisting substance—as, for instance, a carbon filament placed in a vacuum. The particles or molecules of carbon are put into a state of violent vibration, but no decomposition takes place, because of the absence of combining gases. Probably all substances could be burned if we only knew the conditions necessary to bring about their combustion. The sun, for instance, is the greatest fuel reserve in the Universe—the source from which all available energy originated—yet the substances burning there are not those commonly recognised as fuel substances. It has been estimated that the energy due to solar radiation is 70,000 times that of the coal burnt simultaneously. With the cessation of the light and heat of the sun, all plant life will cease on the earth and all evaporation, and, consequently, all life on our planet would come to an end, rivers would cease to flow, the sea would contain all the water there was, even the existence of the two remaining sources of energy—the tides and the internal heat of the earth—would probably also be eliminated, for the movement of the moon in relation to the earth would be altered, and the earth, which is always cooling, would by then have cooled entirely.

But fuel, in the common acceptation of the term, comprises only those carbonaceous substances which are applied by man to the generation of heat or light, the heat being used for the warming of dwellings, cooking of food, the generation of power, or the reduction of metalliferous ores, and in manufacture generally. The fuel may be a solid substance such as wood, liquid such as oil, or gaseous, as, for example, natural gas or gas distilled from solid or liquid fuels.

All fuels, with the possible exception of mineral oils and natural gas, are of vegetable origin, and they all contain carbon and hydrogen. The importance of fuel can hardly be overrated. Without an ample supply of fuel civilisation, as we know it, would be impossible; and, although mankind might continue to exist, it would be in a very degraded form unless some other source of heat were made available (see page 9). Food and fuel are the two necessities of human existence, the latter a requirement which differentiates man from an animal. Even the Esquimaux of Northern Greenland, who live on an icebound surface where there is no vegetation and where coal, if it exists, is not available for use, have to employ fuel in the shape of animal oil, burned in stone lamps.

Until comparatively recent years mankind has depended chiefly on vegetation for the supplies of fuel—wood and charcoal—and, indeed, for long after the discovery of coal these continued to be, in Great Britain, the staple fuel.

In Britain, prior to the Roman occupation, it is exceedingly doubtful whether there were any stone buildings, nor until much later times was the art of masonry applied. Except in the erection of the Barons' strongholds and of Cathedrals, dwellings were of clay and wattle; nor was lime used in agriculture. Iron was a rarity, so neither the limekiln nor the smelting furnace existed in those days, and the want of coal had not arisen. There are extant, as late as the twelfth century, grants made to burgesses for obtaining supplies of wood and peat for their own use, but not to sell, and these in districts where coal existed at shallow depth from the surface, and districts in respect of which we find some of the earliest references to coal mining. The earliest use of coal was, indeed, confined to smiths and lime burners. In the primitive buildings, which existed even up to early Tudor times, wood entering so largely into their construction necessitated placing the fire hearth in the centre of the floor, and as there was no provision for getting rid of the smoke, a fire of coals would have rendered occupation of the dwelling impossible.

Trade in coal in England was not carried on earlier than the thirteenth century, though the existence of coal was known long before then. For example, about 371 B.C., Theophrastus, a pupil of Aristotle, used the word in his treatise on stones, mentioning fossil substances " that are called coals, which kindle and burn like wood coals," which substances were found in Liguria and in Elis, in the way to Olympias, over the mountains; they are used by the Smiths." Probably this is the first mention of true coal, as opposed to charcoal, and the term *lithanthrax* (stone coal) still exists in the Italian form *" Lithanthrace."*

The earliest recorded use of coal (not charcoal) in Great Britain was in A.D. 852, when it is recorded that the Abbot of Peterborough received " twelve cartloads of coal," though some doubt has been expressed by antiquarians as to whether the word translated as " coal " does not mean " peat."

The great industrial era, which had its origin in Great Britain and thereafter spread to all civilised countries, may be said only to have commenced about one hundred and fifty years ago, being largely due to the application of steam to the production of motive power, the outcome of the discoveries and designs of Savory (1698), Newcomen (1710), Watt (1788), and Stephenson (1814). The basic substances which have rendered this great development possible have been the availability of an abundant and cheap fuel in the form of coal, and of the base metals, chiefly iron. After the exhaustion of the world's great supplies of mineral fuel, energy will still be available from the sun, the wind, water power, and the disruption of the atom, and means will doubtless be discovered for the effective harnessing for the service of man of these sources of energy. But the continued existence of some of the base metals would seem, so far as our knowledge at present carries us, to be necessary for the conversion and transmission of energy. So that, though one can imagine civilisation existing without supplies of fuel, without an abundant supply of the base metals, its continuance would be rendered impossible, and some, at any rate, of the base metals will, probably, be exhausted before the deposits of mineral fuel.

The Heating Value of Fuels.—The thermal value of a substance, commonly termed the Calorific Power, is the amount of heat which is given off by the combination of one pound (or gramme) of that substance with oxygen. There are several units in use for expressing thermal values. Those in most common use are:

> The British Thermal Unit (B.T.U.), which is the amount of heat required to raise one pound of water 1° F., the temperature of the water being 60° F. to commence with.
>
> The Scientific Unit or Calorie, which is the amount of heat required to raise one gramme, or sometimes one kilogramme, of water from 0° C. to 1° C.
>
> The British-French Thermal Unit, or "pound-calorie," the amount of heat required to raise one pound of water 1° C.

The first and the last are the units in commercial use, and are easily convertible; thus, by dividing the B.T.U.'s by 1·8, they are converted into pound-calories.

If the chemical analysis of a fuel is known, we can determine with some degree of precision its calorific power by calculation of the heat expended in the burning of the elements contained therein which generate heat. Thus, when carbon is burned to form carbon-dioxide (carbonic acid gas), the heat expended in the process is equal to 174,500 B.T.U.'s, but seeing that twelve parts of carbon are required in the reaction, the combining weight of carbon being twelve, the calorific power of carbon, when burnt to carbon dioxide (CO_2), is 14,542 B.T.U.'s. If the combustion is incomplete and carbon monoxide (CO) is formed, the value is less, which points to the necessity of complete combustion if the best heating value is to be obtained from the fuel.

The other substance next in importance to carbon from the point of view of heating, which is contained in all fuels, is hydrogen, which is burnt to form water, the thermal value of hydrogen in the reaction being ($2H + O = H_2O$) 123,048 B.T.U.'s, but as this is due to the combustion of two parts by weight of hydrogen, the calorific power will be half this figure, or 61,524. Some fuels contain a small quantity of sulphur, which must be added.

A calculation made on the above basis can only be regarded as a close approximation to accuracy, for we do not know the heat of formation of the constituents of solid fuels, so that it is impossible to determine with exactitude the heat of combustion of such fuels, nor is there certainty as to the value of carbon burning to form carbonic acid gas (CO_2). The figure taken is 8080° C. Favre and Silberman give 8080° C. for wood charcoal, 8047° C. for gas retort carbon, 7762° C. for native graphite, and 7770° C. for diamond.

In the case of gaseous fuels, the carbon is in the gaseous form and will have, therefore, a higher calorific power.

A factor which frequently enters into calculations in relation to fuels is their evaporative power—that is, the amount of water which a given quantity of the fuel will evaporate at a temperature of 212° F. As the latent heat of evaporisation is 967, that number of units of heat are required to convert one pound of water at 212° F. into vapour of that temperature. Thus the evaporative power of carbon is $14{,}544/967 = 14{\cdot}9$, so 14·9 pounds of water would be evaporated by one pound of carbon.

In the case of hydrogen, the figures would be $61{,}524/967 - 9 = 54$. A pound of hydrogen is contained in nine pounds of water which has to be evaporated, hence we have to make the deduction of nine. As a matter of fact, in the case of solid fuels, such as coal, the evaporative power of fuels is generally determined by experiment, using for the purpose an instrument termed a calorimeter. The instrument in most common use for this purpose is either a Thompson or a Rosenhain calorimeter, in which the fuel is burnt in water.

But it does not suffice to know only the actual heating power of a fuel. We ought to know what the temperature would be if the fuel were burnt under perfect conditions as to the correct amount of oxygen, and in the best managed factories and power stations great care is devoted to this matter, the inlet of air being carefully adjusted and the products of combustion determined and measured with a view to ascertaining the degree of perfection in combustion attained.

CHAPTER II

VEGETABLE FUELS, WOOD, PEAT AND REFUSE

Wood constitutes man's earliest form of fuel, and largely continues to supply his needs in that direction. It is a form of fuel which is being constantly replenished, and, in most countries, is easy of access. Green wood—that is, wood before being dried or seasoned—has a high moisture content varying, according to the species of tree, from twenty-six per cent. to fifty per cent. Most freshly felled timber contains fifty per cent. of moisture. The moisture content is, of course, highest in that season of the year when the sap is running. After being air-dried, the moisture content of the wood is considerably less, ranging between fifteen and twenty per cent. Dry wood is made up on the average of about twenty-six per cent. of fixed carbon, seventy-two per cent. of volatile matter, and two per cent. of ash. Air-dried wood, owing to the moisture content, has, on the average, a calorific power of only about 7,000 B.T.U.'s.

Both the fixed carbon and ash contents of wood are much lower and the volatile matter much higher than in the case of coal, because in the formation of coal a process of carbonisation is carried on which tends to reduce the percentage composition of the volatile matter and *pro tanto* to increase the fixed carbon content. The increased ash content in the coal is due largely to the introduction of adventitious matter.

Charcoal

By "carbonising" wood—that is, by converting it into charcoal by means of distillation, just as when coal is converted into coke—the calorific value of the fuel is enhanced. In the case of charcoal, thermal values as high as 13,500 B.T.U.'s, or more, are obtained. Charcoal is a fuel of great purity; indeed, for centuries, it was the only fuel used in the smelting of iron ore, and, probably, its gradual abandonment in favour of coal and coke was due, more than anything else, to the increasing scarcity of suitable wood for its manufacture. Charcoal is, however, still extensively used in North America, Sweden, and Styria. As the bark of trees has a much higher phosphorus content than the interior part, it should be removed before subjecting the wood to carbonisation for smelting purposes.

An inventory of the timber resources of the world does not exist and would be difficult of achievement. Some years ago, the late President Roosevelt put forward the suggestion of the drawing up of a world inventory of economic resources, but only so far as the United States is concerned has such an inventory been effected. The consumption of the world resources of timber is proceeding at a far greater rate than their replenishment, and this with an increasing population. Vast as these resources still are, the day is not far distant when serious consideration must be given to the question of a possible dearth of wood, if a vigorous world policy of reafforestation is not soon inaugurated and carried out.

Charcoal would probably be more extensively used for smelting were it not for its friability. As it is, it can only be used in small furnaces where the crushing effect of the burden is not great. Unfortunately, the waste in its production is very considerable, and by the old process of carbonisation of wood, in which it was piled up in heaps, only about sixteen per cent. of charcoal was obtained, but even when carried out in retorts as in modern practice, the residual charcoal is only twenty-seven per cent. of the original fuel.

Wood is measured by the cord, a cord being 4,000 pounds weight, and according to T. W. Pritchard (*Journal Soc. Chem. Ing.*, 1912, p. 418), the yield of products per cord of wood when carbonised at a temperature of 625° F. is forty gallons of best turpentine, sixteen gallons of light oils, 128 gallons of heavy oils, and 950 pounds of charcoal.

Charcoal, besides its high carbon content, which may be taken as averaging ninety-five per cent., contains one-half per cent. of hydrogen, one and a half per cent. of oxygen, and three per cent. of ash, but the gases mentioned are the result of absorption, which power in charcoal is considerable. It is also hygroscopic. If the wood is carbonised at low temperatures, red charcoal is formed, known to the Germans as "rothkole" and to the French as "charbon roux," which contains a higher percentage of combustible matter than charcoal made under high temperature conditions.

Charcoal cannot be recommended as a domestic fuel, because of the generation in burning it of that very poisonous gas, carbon monoxide. That now used is made in closed kilns or retorts, but most of that made in Great Britain is in the nature of a by-product in the manufacture of acetic acid, in the destructive distillation of wood in iron retorts. About three million tons of wood are so distilled annually, of which about half is produced in the United States of America. The principal products obtained are charcoal, acetate of lime, wood alcohol, and tar.

In countries such as the United States, Canada, Australia, and in some parts of Europe, where great forests exist and where timber-felling is much practised, *sawdust* and *wood refuse* constitute an important fuel for steam raising purposes in the wood working factories. In America, too, waste-wood gas producers are in use for the generation of power.

A vegetable substance which is largely used as a fuel in sugar-cane growing countries is *Bagasse*, which is the tough fibre remaining after the sugar has been extracted from the cane. The combustible matter in this residue varies from as low as thirty-five per cent. to as high as sixty per cent., and the moisture and ash together from forty to sixty-five per cent., the variation being in respect of the sugar growing districts. The calorific value of dried bagasse is about 8,300 B.T.U.'s. When wet it is only 3,620, owing to its containing about 56·7 per cent. moisture.

Straw, rice husks, spent tan, and cotton stalks are also all used as combustibles in various parts of the World, and all, in order to afford the best results, require to be burnt under water tube boilers with large combustion chambers so that large quantities of these substances of low calorific value can be consumed.

COWDUNG

Dried cowdung makes an excellent fuel, and on the South African veld and the Argentine, where other fuel is not available, is much used as such by the natives, and in parts of India by the peasant, though in India, wherever wood exists in plenty, it might be devoted to manuring the land to better purpose than for burning. The writer used it for many weeks at his camp in South Africa, and found it a most serviceable fuel.

PEAT

An important source of fuel is *peat,* which is the remains of different kinds of aquatic plants, including reeds, rushes, sedges and mosses, but most largely of plants of the genus sphagnum. It occurs in bogs or morasses of from five to thirty feet in thickness, which are limited to countries of temperate climate, no bogs being found between latitudes 45° N. and 45° S. The disintegration of the vegetable growth in depressions with a floor impervious to water, is brought about by moist atmospheric oxidation and by anærobic bacteria, yeasts, moulds, and fungi, in stagnant or semi-stagnant water. The rate of growth of peat bogs is variable, but it has been estimated that in the case of some extensive British bogs, these have increased in vertical thickness by from three to five feet since the date of the Roman invasion.

The World resources of this class of fuel are immense. Russia alone has at least 65,000 square miles of peat deposits, Canada, 37,000 square miles. In the aggregate, taking Europe, Canada, and the United States of America, there are 194,000 square miles of peat. The density of peat varies between 0·25 and 1·4, and as to the weight, Sir Robert Rane has given the following figures:

1 cubic yard of light (domestic) peat	500 lbs.
1 „ „ „ good peat	900 „
1 „ „ „ densest peat ...	1,100 „

In Germany, the yield per square kilometre (0·386 square miles) for a depth of five metres (16·4 feet) has been estimated at about 800,000 tons of air-dried peat. Probably, therefore, the world's resources of (air-dried) peat amount to 200,000 million tons.

From the fact that the water content of peat is frequently as high as ninety per cent., it will be realised that it is difficult for it to compete successfully with other fuels of higher calorific value, where such are readily available, a great quantity of wet peat having to be handled in order to obtain a comparatively small quantity of serviceable fuel. The best Irish peat (Kilbeggan), when dried, contains 61·04 per cent of carbon, 6·07 per cent. of hydrogen, 30·46 per cent. of oxygen and nitrogen, and 1·83 per cent. of ash, and has a heating value of 9,160 B.T.U.'s.

Of late years mechanical power has been applied to the winning and treatment of peat, especially in Sweden and Germany. The most recent process designed for the drying of peat is the "Peco," a plant of which type is established near Dumfries in Scotland, where it is claimed that the raw material can be dried down to ten per cent. moisture content, and that sixty-five per cent. of the peat is recoverable—that is to say, thirty-five per cent. of it is used in working the process, which is the best result yet obtained by any process.

Peat briquettes make a serviceable fuel. These contain about eight per cent. of moisture and yield charcoal of high quality, but most of the peat produced is used in the natural and air-dried state. Probably the direction which offers the most advantageous use for peat fuel in the future is in the form of carbonised briquettes. Several processes exist for the carbonisation of peat and the recovery of the by-products. At Beuerberg in Bavaria, where the Ziegler process was in operation, the semi-coke contained 73·89 per cent. of carbon and 2·5 per cent. of ash, the calorific value being 12,000 B.T.U.'s. The volume of gas obtained was 6,759 cubic feet per ton of dried peat, and the other by-products recoverable were:

Ammonia sulphate	900	lbs.
Acetate of lime	13·2	„
Paraffin	7·15	„
Creosote	31·00	„
Asphalt	0·40	„
Menthal alcohol	0·65	galls.
Light oils	2·80	„
Heavy oils	0·95	„

The manufacture of "producer" gas from peat, in respect of which there are several methods, has been practised in Germany for some time. The processes are mostly based upon the Mond system, and have proved fairly successful. In Sweden, during the war, locomotives were successfully fired with peat dust.

As to the annual output of peat, no statistics of much value exist, but probably the largest producer is Ireland, with about six million tons annually of air-dried peat, for in that country peat may be regarded as the national fuel.

The Utilisation of Waste: Town Refuse

Of late years there has been a great movement towards utilisation of waste products. An enormous amount of waste and garbage occurs in all large towns, of which, though its calorific value is low, use is now made by burning in "destructors" to raise heat for the generation of steam. The calorific value of the refuse varies considerably as between different districts, for, naturally, in a coal mining neighbourhood, where coal is cheap, there will be waste of coal, with the consequence that the town's refuse will have a higher thermal value than that from a town far removed from a colliery centre and where coal is dear. The pounds of water evaporated per pound of refuse burnt varies as much as from 0·88 to 3·53; the former figure is in respect of Rotterdam and the latter Aberdare in South Wales. But as Mr. J. B. C. Kershaw says in his useful little book, *The Use of Low Grade and Waste Fuels for Power Generation*, it would seem probable, in view of the increased price of fuel and the urgent necessity for the practice of economy on the part of all sections of the population, that English house refuse will contain, in future, more cinder and less unburned carbon than in the past, and it will be wise, therefore, to assume that the average calorific value of town's refuse, when calculated upon twelve months' working of the destructor, is about 2,160 B.T.U.'s per pound, and that only one pound of water can be evaporated per pound of refuse burnt for steam-raising purposes.

CHAPTER III

BROWN COAL, LIGNITE, AND SUB-BITUMINOUS COALS

ALL coal is composed of vegetable matter which has, in the process of time, and owing to the operation of certain agencies, undergone change of state. The process through which an organic body passes in order to become a fossil is termed fossilisation; some fossils —for example, some shells and bones—are the actual remains of the original body, others have undergone certain changes produced by pressure, deprivation of organic matter originally present, and infiltration of mineral matter. Some fossils are formed by " replacement "; thus, in the case of silicified wood, the particles of carbon have been replaced by silica, the fossil showing all the fibrous structure and rings of growth of the original tree exhibited in flint, the wood presumably having slowly decayed in a solution containing silica; and examples could be given of other cases of replacement where the replacement matter was pyrites, malachite, magnesite, or other mineral. In the transition of vegetable matter to coal the process is, however, somewhat different. A process has taken place whereby the vegetable matter has lost much of its oxygen and hydrogen; thus, whereas the ratio H/C in dried beechwood, for instance, is 8·22 and in peat a little higher, in brown coal it becomes 11·84, in ordinary bituminous coal 12·48, and in anthracite 27·21. Coal is evidently the result, to a large extent, of bio-chemical action, the agents of the transformation of the cellulose into peat substance being saprophytic fungi and bacterial ferments, the progressive elimination of oxygen and hydrogen taking place partly as water and partly as carbon monoxide, carbon dioxide, and marsh gas. From this it must not be inferred that brown coal is the descendant of peat and true coal of brown coal. In many cases it probably is so, but it does not necessarily follow that the chemical sequence is indicative of a geological sequence of peat to true coal.

The brown or black opaque ground substance of the coal is accounted for as the final product of the destruction of the plant tissues by the bacteria. The "crystalline" structure and cleavage characteristic of many true coals is due to pressure—as a simple experiment with an hydraulic press and mud will demonstrate—the pressure being exerted by the superincumbent strata, the mass of decayed vegetable matter being overlaid by the deposition of layers of sand and mud due to the sinking of the land.

Brown coal, frequently though erroneously termed lignite, is an immature coal and young geologically, belonging to the Tertiary Age, whereas the true coals occur lower down in the geological scale, chiefly in the Carboniferous Division. The brown coal of Germany is an amorphous brown earthy substance, containing occasional deposits of true lignite in bands, probably the result of fossilised trunks and branches of trees which grew in the marshes, existent in the hollows of the land surface, being deposited *in situ*. Lignite, properly speaking, is the term applied to coal which has retained its woody structure; it is a French word, derived from *Lithanthrax Lignius,* used by Wallerius (1775) for woody coal.

Immature coals, other than brown coal and true lignite should, for purposes of identification, be included under the term *sub-bituminous,* instead of designating them, all and sundry, as lignites, which is the common and confusing practice, the words "brown coal" should be used only to describe those coals which are brown and "lignite" those which have a woody structure—usually black or dark brown, and which, on drying, split up into slabs. Some young coals are quite black; indeed, cases exist of brown coals gradually grading into black coals. A characteristic of nearly all immature coals is a high moisture and volatile hydrocarbon content and low fixed carbon content. Roughly speaking, the older the coal the higher the fixed carbon content, it being increased at the expense of the volatile hydrocarbons—for example, anthracite, and, older still, graphite, which is practically pure carbon.

The composition of German brown coal may be said to vary in respect of moisture from forty to sixty per cent., of carbon from twenty to thirty-five per cent., of oxygen and hydrogen from eight to ten per cent., and of ash from five to twenty per cent. Germany is quoted in this instance as being the greatest producer of brown coal in the World.

Professor Elwood A. Moore, the American authority, gives the following as an average composition, compiled from analyses of brown coals from all parts of the World.

Moisture	14·42	per cent.
Volatile matter	40·78	,,
Fixed carbon	36·00	,,
Ash	9·32	,,
Sulphur	1·14	,,

The calorific value of brown coal and lignites varies greatly. Thus the brown coals of Germany have a calorific value of from 3,270 to 5,760, the Canadian *lignites* from 8,000 to 9,600, the New Zealand *lignites* of from 6,800 (Central Otago) to 11,000 B.T.U.'s, (Waikato), though the last named is not really a brown coal, being black and glossy, but an immature or sub-bituminous coal.

Deposits of brown coal usually exist at shallow depths, being overlaid by and inter-stratified with clays and gravels.

There exists no estimate of the brown coal resources of the World, but the Geological Congress, which met in Toronto in 1913, arrived at the World's resources of sub-bituminous coal (brown coal and lignites and immature coals generally) as being 2,997,763 millions of metric tons (a metric ton is equal to 2,204·6 lbs.), or by continents:

Europe	36,682	million tons
Asia	111,851	” ”
Africa	1,054	” ”
America	2,811,906	” ”
Oceania	36,270	” ”

The Congress adopted as the basis of their classification of coal the fuel ratio

$$\frac{\text{Fixed Carbon}}{\text{Volatile Matter}}$$

and in the case of sub-bituminous coals, the split volatile ratio

$$\frac{\text{Fixed Carbon} + \text{Volatile Combustibles}}{\text{Hydroscopic Moisture} + \frac{1}{2}\ \text{Volatile Combustible}}$$

and divided the sub-bituminous coals into Class D_1 which corresponds to sub-bituminous coal or compact black lignite, and Class D_2 which corresponds to lignite or brown coal.

In the British Isles the resources of brown coal are negligible. In Germany the deposits are very numerous, and sometimes of great thickness, the more bituminous seams ranging from twenty-five to sixty-five feet. Only one large deposit attains to a thickness of 165 feet, but the lean seams reach to a thickness of 330 feet. The most remarkable deposit of brown coal in the World is in the Latrobe Valley, Victoria, Australia, where a tract fifty miles in length contains, within a depth of 1,000 feet from the surface, at least 31,144 million tons of coal, and where the thickness of the beds in the aggregate is seven hundred and eighty-one feet. The British Empire is rich in these coals. In Canada there are enormous resources of subbituminous coal, as also in New Zealand. In the United States of America the supplies of such bituminous coal are particularly abundant. The World's output of lignite and brown coal for 1927 was just under 200 million tons, of which Germany was by far the greatest contributor with 148 million tons.

It is worthy of remark that the fields of brown coal and lignite are coming more and more into requisition—for instance, in Australia a very few years ago practically no brown coal was produced, now a flourishing industry has arisen. Germany, it is estimated, has, at the present rate of production, sufficient brown coal to last for 150 years at least.

We have to look to Germany, and, latterly, to Victoria, Australia, in order to see to what uses brown coal can be put as a fuel. The industry in Germany has been carried on for many years—as in Austria, also—but since the Great War, when the Upper Silesian coalfield was transferred to Poland and the Sarre coalfield to France, the brown coal industry was greatly developed and constitutes a very important and flourishing industry. The chief consumer is the electric power industry of that country, it being the source of over forty-one per cent. of the electric power generated therein.

While all the brown coalfields of Germany serve as fuel bases, the deposits of Central Germany differ from the other, and, indeed, from all other deposits of brown coal so far exploited, wherever situated, in that on them are founded an important chemical industry, which has flourished since the middle of last century. It is interesting, too, when we hear so much in these latter days of the low-temperature carbonisation of coal, to learn that in Central Germany it has for long been practised successfully on a large scale in connection with brown coal.

One of the principal factors contributing to the success of the brown coal industry of Germany is the low cost of producing the material, due to the fact that, the thick deposits being near to the surface, it is possible to remove the overburden by means of immense dredgers or mechanical excavators and to work the brown coal "opencast" by the same means. Some of these dredgers have a bucket capacity of over seventeen cubic feet each, and a total producing capacity of 211,800 cubic feet per shift of ten hours. On the exhaustion of a deposit, the excavation is filled in with gravel, sand, and earth and reconverted into agricultural land.

It is usually reckoned that one ton of German true coal is equivalent in heat value to 2·8 tons of German brown coal. The reason for it being an economic proposition to work German brown coal, which is so much inferior to the true coal, is the fact that it is produced at such a low working cost, a cost much below that at which the true coal can be raised.

As indicating what can be done with brown coal, reference may again be made to Germany. If we take the figures for the year 1923 we will find that fifty-two million tons of brown coal were briquetted and fourteen million tons were treated by low temperature carbonisation for the production of oil and "coke,"* the remainder being used in the raw state for heating houses, raising steam and, in some cases, where rich in bitumen, for the extraction of montan wax.

In Australia, where in 1924 only 127,490 tons of brown coal were raised, and last year, 1928, 1,479,639 tons, the coal is employed in the generation of electrical power to a large extent, there being established at Yallourn, in the State of Victoria, a 50,000 kilowatts station. The net calorific value of the raw brown coal is here only about 4,800 B.T.U.'s, with sixty per cent. moisture, but by briquetting, the moisture content is reduced to thirteen per cent. and the calorific value raised to about 9,000 B.T.U.'s. The briquetting works are built on the basis of a maximum output of 100,000 tons per annum. It is claimed for the briquettes that they are at least equal in quality to the German brown coal briquettes. The relative average costs of working brown coal and true coal in Germany are about two marks per ton for brown coal and sixteen marks for a black or true coal.

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* The carbonised coal is spoken of as "coke," but as a matter of fact, brown coals do not cake on the application of heat.

It has not been found commercially practicable to convert the carbonised brown coal into briquettes in Germany; the "coke" is too soft and the ash content too high. So the briquettes are made from the raw coal (as also at Yallourn in Australia), which is screened and dried down to twelve to seventeen per cent. moisture and then compressed at a pressure of 1,200 atmospheres into briquettes. On the other hand, the Waikato lignite, in North Island, New Zealand, which has approached nearer maturity than the brown coal, and is a glossy, black, sub-bituminous coal with low ash content, makes an excellent briquette, with a calorific value of 13,507 B.T.U.'s. The "coke" from German brown coal is burnt in a special form of cooking stove, common in Central Germany, and as so used is a very satisfactory fuel.

The carbonisation of brown coal at low temperature —the expression "low temperature" being used in contra-distinction to "high temperature," the latter being applied to the conversion of true coal of a coking quality into metallurgical coke or gas coke—has been a flourishing industry in Central Germany since about 1870, the form of oven or retort used being the well-known Rolle Oven, devised by the late Dr. E. Rolle between the years 1865 and 1870, and, though efforts have not been wanting to improve on this type, it still holds first place. The chief product contained in the tar obtained in the distillation of the brown coal is the paraffin wax, but not all brown coals, by any means, are rich in paraffin wax.

Some brown coals, probably all, contain more or less of a substance which the Germans term "bitumen," and if the coal is treated with naphtha or benzol, this is extracted and is reducable to a wax known as montan wax, a substance which has a melting point of between 80° and 85° C. and is used extensively in the manufacture of boot polish, cable wax, special varnishes, lacquers, electrical insulation, gramophone records, etc. When bleached it becomes pale yellow, almost white, in which form it is used for making light polishes, and as an addition to paraffin wax, in the manufacture of candles, giving them an ivory appearance. The present price of raw montan wax is about £22 10s. per ton, or bleached, £87 10s. per ton.

Only a few of the brown coals of Central Germany are sufficiently rich in bitumen to permit of the profitable extraction of montan wax. For this purpose, the coal must contain at least ten per cent. of bitumen extractable with hot benzol in a laboratory test. There used to exist—it is exhausted now—in the neighbourhood of Weissenfels, near Halle, a band of brown coal, from six to nine inches in thickness, of a pale grey colour, which gave it the name of "white coal," so rich in bitumen that it constituted a veritable "gold mine." It contained upwards of sixty per cent. of bitumen and was distilled to recover it as tar oil; the mineralogical name for it is Pyropissite, and it is nearly related to Ozokerite.

CHAPTER IV

THE ORIGIN AND VARIETIES OF COAL

THAT coal is the result of the transformation of vegetable matter by the elimination in great part of oxygen and hydrogen is undoubtedly true, though as to the means of its conversion we know little. The old belief regarding its origin was that of vast marshes or peat bogs covering the land in which flourished dense forests of giant club mosses growing in a tropical or semi-tropical and very humid atmosphere, and that coal is mainly constituted of the transformed remains of these club mosses and their spores. This theory prevailed in Huxley's time; it was accepted by him and held the field unmodified until quite recently. Whilst in great part a true explanation of the origin of coal, it is not the complete explanation, for we know now that actual forest trees existed in the great carboniferous period, and that woody matter entered largely into the composition of the original vegetable mass of some coals. It has been shown, by M. Grand'Eury, for instance, that the bark of *cordaites* is an important ingredient in the coalfield of St. Etienne, in Central France, and Dr. Marie Stopes has proved the same to be true of many British coals, As the writer has said elsewhere :* "It is clear, therefore, that coal is made up of many constituents : (*a*) woody or xyloid substances, which are so characteristic of lignite coal, called by some 'anthraxylon' from anthrax (coal) and xylon (wood); (*b*) canneloid material, consisting largely of spores of cryptogamic plants, of which cannel coal is chiefly composed; (*c*) resinous matter occurring largely in lignite, but rarely in cannels; (*d*) macerated material mixed with woody matter and best described as débris, as it contains all the previous-mentioned substances; (*e*) the 'fundamental matter' of White and Thiessen, which is the colloidal ground mass in which the other constituents are embedded, and which is composed of the more readily decomposable parts of the vegetable matter."

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* Under heading "Coal" *Encyclopædia Britannica,* 14th Edition.

One can witness at the present day, on a small scale, in the Great Dismal Swamp of North Carolina and Virginia, what probably took place on a grand scale many millions of years ago in the great Carboniferous period. This is a fresh-water swamp of peat and forest, which is about thirty-eight miles north and south by twenty-five miles east and west, and is estimated to have had an area originally of 2,200 square miles before drainage and cultivation made inroads on it. Shaler, in his "Geology of the Dismal Swamp District," contained in the tenth *Annual Report of the U.S. Geological Survey,* describes a series of occurrences in connection with this swamp, which are a remarkable exemplification of what, we may suppose, was the sequence of events in the formation of the great coalfields of the World. This sequence in the case of the Dismal Swamp was as follows:

First a subsidence causing the formation of the Pliocene Plateau, then elevation allowing of the erosion of the plateau followed by subsidence permitting of the deposition of non-fossiliferous sands, then elevation again which allowed of carving of the surface, followed by subsidence and the formation of what is known as the Hausemond escarpment, re-elevation and development of valleys and finally, sinking, which is now taking place.

As against the "Growth in place" theory or "The peat to anthracite" theory, as Arber terms it, is the "Drift" theory, under which it is maintained that the vegetable matter from which the coal is formed was transported by water to its present position. The advocates of this theory are led to take this view from the fact that the great mass of the rocks of the coal measures was undoubtedly water-deposited; that the coalfields are too extensive, so they maintain, to have originated under estuarine conditions such as exist at the present time; and that coal is usually a stratified rock and that it is difficult to account for the splitting up of seams under the *in situ* or *growth in place* theory. But as we have seen from the example given above of the Great Dismal Swamp, the *in situ* theory is not only possible, but most probable. But that there are cases of coal having been deposited as water-borne material would seem undoubtedly true in some cases, as, for instance, in that of the small coalfields of Central France. The preponderance of evidence is in favour of the great coalfields of Britain having originated *in situ*.

One can imagine during the coal measure period the vast marshes which covered the greater part of the surface of the land, the dense growth of cryptogams and forest trees luxuriating in a humid semi-tropical atmosphere, an atmosphere from which the carbonic acid gas existent during the magmatic state of the World ages before had not been entirely extirpated, though eventually to be so by means of the absorbent quality of this same vegetation. What an extraordinary sight must have been presented to the human eye had man been on the earth during the great Coal epoch. Vast tracts of dense vegetation growing and rotting in an atmosphere, the humidity of which must have far exceeded anything known at the present day. What a pitiful waste it must have appeared to man, almost exclusively concerned, as he would have been (and as he now is) with matters of the moment, indisposed to project his mind into the future and unable to realise the untold value and blessing to humanity this rotting vegetation would be in the form of coal millions of years later; but to the Great Architect of the Universe "a thousand years are as one day and one day as a thousand years."

Coal is frequently, though incorrectly, spoken of as a mineral, whereas as a matter of fact it is a rock in the geological sense. The word "coal" is the modernised form of *kohle*, used in England before the Norman Conquest to designate coal (charcoal). The Cornish word is *kolan*, the Irish *qual*, and the Welsh *glo*. The German and Dutch word for coal at the present day is *kohle*, and the Swedish *kol*.

Coal, besides the purely coal substance, contains a varying quantity of mineral matter which forms the ash when coal is burnt, consisting chiefly of silica, calcium, and iron pyrites, sulphur and minute quantities of phosphorus, the two latter being very detrimental when the coal, or coke made therefrom, is used for smelting metal ores. Some of these impurities were in part contained in the original vegetable matter—for example, the silicia, sulphur and phosphorus—and, decaying vegetable matter having the property of converting the iron contained in it into sulphite of iron, we see this in the coal in the form of crystalline iron pyrites. Apart from these impurities inherent in the coal, there is a source of adventitious dirt derivable from the bands or layers of shale (clod, clift, hussle, stone, or dirt) interstratified with the coal, and from the roof and floor of the seam, and this is the dirt which it is possible, in great measure, to remove from the worked coal by sorting, washing, or dry cleaning; the inherent ash cannot, except, possibly, to an almost negligible degree, be removed from the coal.

In the great majority of cases coal seams are immediately underlaid by a floor of argillaceous shale or fireclay, which constituted the soil in which the coal plants grew—another argument in favour of the *in situ* theory of formation—the roof being usually a rock of a much more arenaceous character.

A seam of coal may not necessarily be of the same character vertically throughout—in fact, in most cases it is not, especially in the case of thick seams—but even where the seam is composed of one class of coal throughout its entire thickness, it comprises, in many cases, laminæ of bright coal (the *Glanz Kohle* of Germany) and dull coal (*Matt Kohle*) divided by an amorphous, powdery, carbonaceous matter termed "mineral charcoal."

Although the chief source of the coal of the world is the great Carboniferous formation, and, in particular, the Coal Measures division of that formation, the occurrence of coal is not restricted to that period; for instance, in Scotland there is a small coalfield (Brora in Sutherlandshire) which is of Lower Oolitic age. The coal of the Pacific slope of Canada is of Cretaceous origin. The South African coals are probably of Triassic age. The coalfields of Russia belong to the Lower Carboniferous and Old Red Sandstone formations.

There are a number of different classes of true coal, the one class graduating into the other, the important factor in the classification being the proportion of volatile matter to fixed carbon in the coal substances—that is, exclusive of the ash content. This basis of classification was adopted by the International Geological Congress at Toronto in 1913, which included under the term "Coal" the extremes of sub-bituminous coal (brown coal, lignite, and immature coals generally) and anthracite, as well as bituminous coals. On this basis it arrived at four main divisions and three subdivisions. But, however satisfying scientifically the classification in question may be, there is little doubt but that the public, commercial and otherwise, will continue to regard and speak of coal as being either a coking or non-coking coal, a house or a gas coal, a smelting or a steam coal, or an anthracite or a semi-anthracite.

Coals highest in volatile hydrocarbon content are gas coals; the most remarkable of the gas coals, which is almost in a category of its own, is "cannel" coal—

or originally "candle" coal, from its quality of continuing to burn when ignited—in appearance pitch-like, smooth, and of a dull black colour, having a conchoidal fracture and not soiling the fingers when handled, and when scratched giving a brown streak. It would appear to be a "drift" deposit often being found in basin-shaped formations with absence of a true underclay. The value of cannel as a gas coal consists in the fact that it contains a higher percentage of heavy hydrocarbons than any other coal. Some cannels are very rich in volatile matter; that at Newbattle, Scotland, yielding 13,720 cubic feet of gas of 35·24 candle power per ton. It is a requirement of a good gas coal that it should yield about 10,500 cubic feet of gas (as measured when the temperature of the external atmosphere is 60° F. and the barometric pressure thirty inches) with an illuminating power equal to sixteen standard candles. The sulphur content of the coal should be under one per cent., so that the amount of sulphuretted hydrogen on distillation be as low as possible, for not only is it an evil-smelling and poisonous gas, but it acts as an adulterant to the illuminating gases.

A *coking coal* is one which is possessed of the quality of intumescense or swelling up on the application of heat. It is usually a friable coal. The caking quality would seem to be due partly to physical and partly to chemical characteristics. Some coals which do not readily coke if ground fine and subjected to compression, may be made to do so. Anthracite, which has a high fixed carbon and a low oxygen content, and lignites and brown coals, which have a low fixed carbon but a high oxygen content, do not coke. It has been found, however, in the laboratory, that if hydrogen be added to anthracite, it renders it to some extent cokable. It would seem, therefore, that a coal, in order to be a good coke-making fuel, should contain a comparatively high hydrogen content, and in the case of high-temperature or metallurgical coke used for the reduction of ores, it should have a low phosphorus and sulphur content, though in the basic process of steel manufacture, so far as phosphorus is concerned, this is not of such importance, as basic slag rich in phosphorus is a valuable product. A high-class coking coal would have some such analysis as the following, the example being that of a well-known Durham coking coal (from Brancepeth Colliery), from which the percentage of coke obtained was 72·8:

Fixed carbon	67·31	per cent.
Volatile hydrocarbons ...	25·61	,, ,,
Sulphur	0·78	,, ,,
Ash	5·10	,, ,,
Moisture	1·20	,, ,,
Phosphorus	0·005	,, ,,

The purest *coke* in the World is Ramsay's Garesfield (Durham), with

Carbon	97·6	per cent.
Sulphur	0·85	,, ,,
Ash	1·55	,, ,,

Nearly all coals can be applied to domestic heating. It is largely a question of convenience and price as to what class of coal is employed as a *house coal*. For this purpose one does not require a coal that gives too fierce a fire, such as a steam coal would, but there should be a bright flame, little ash, and that not floculent, but cindery, or the housemaid complains of the dust that is made! The fire should not require frequent poking as would be the case were a coking coal used. The coal should light and burn easily, which would not be the case with an anthracite or semi-anthracite. The coal should not decrepitate easily, otherwise there will be too much small coal, and small coal does not burn well owing to the difficulty of insuring that the necessary air is supplied to the particles of coal in order to obtain good combustion. The finest house coal ever put on the market was that from the famous High Main Seam of Wallsend Colliery, near Newcastle-on-Tyne.

A manufacturing or iron-smelting coal, though raw coal is seldom applied in these days to the smelting of iron, should be low in phosphorus, sulphur and ash content and have a high fixed carbon content. The phosphorus and sulphur are detrimental to iron, and the ash not only goes to form slag but, being in the nature of an adulterant, detracts from the heating power of the coal.

In a *steam coal*—that is, a coal used for the raising of steam, whether under stationary boilers, in locomotives, or ships—the items of importance are the heating power, the nature of the ash, and the sulphur content. As to the first, the coal should have a sufficiency of hydrocarbons to permit of easy ignition and consumption of the fixed carbon; beyond this the volatile matter conduces to the formation of smoke. As incombustible matter reduces the value of a coal, the ash should be low and of a non-fusible character, fusible ash forms clinker, which is injurious to the firebars, necessitates considerable stoking and loss of heat, so the ash should be of the light, soft kind, usually white. Lime and magnesia have a fluxing influence in ash; these, and the presence of a high oxide of iron content (existing in the coal as iron pyrites—that is, sulphide of iron) conduce to the fusibility of the ash, a feature which is chiefly governed by the relative proportion of the several constituents rather than by the presence of any one of them in excess. Sulphur also acts detrimentally, forming sulphurous acid on burning and eating away the fire boxes and being detrimental to health and injurious to vegetation.

Anthracite is coal from which nearly all the volatile hydrocarbons have been expelled—in fact, it may in many instances be regarded as metamorphosed bituminous coal. Sometimes the loss of hydrocarbons is due to heat generated by pressure occasioned by earth movements, sometimes to the proximity of volcanic intrusions and overflows, but the cause of conversion of the coal-forming matter into anthracite was, in some cases at any rate—for example, that of South Wales, which is the purest in the World—bacterial action on the vegetation which was of a somewhat different kind from that in the lower lying land surface, though continuous therewith, and was longer above water than the latter, allowing of more extensive bacterial action. If, as in the case of the South Wales anthracite, the seams of which are extensions of the bituminous seams in the east of the field grading into steam coals with lower volatile content as they pass to the west, and thence into semi-anthracite, and finally into pure anthracite in the north-west of the field, it has been the result of the effect of heat on bituminous coal, by driving off the volatile hydrocarbons, it would be natural to suppose that the percentage of ash in the coal would have increased *pro rata* with the loss of volatile matter, but such is not the case. The ash content of the anthracite is not only no more than in the bituminous and steam coals, but actually, in some instances, lower. The folding, too, would be a very slow process and the heat generated would, in consequence, be dissipated. The volatile hydrocarbon in anthracite, including in that term semi-anthracite (termed in South Wales "dry" steam coal) as well as pure anthracite, ranges from twelve to four per cent. If we take the ratio carbon/volume of hydrocarbon: in the case of semi-anthracite, the proportion varies from 12 : 1 to 8 : 1, and in that of hard dry anthracite from 5 : 1 to 10 : 1. Anthracite is hard, compact, glossy, and difficult to ignite. It burns without flame, giving out great heat. It is employed chiefly for malting, and the drying of hops—where a steady heat is required—central heating, hot-house stoves and for the generation of producer gas. It is sometimes used for smelting iron, but coke is usually found to be cheaper and more efficacious. Though its heating power is so great, it is unsuitable as a steam coal, owing to the difficulty of ignition and its hard, compact structure, unless forced draught is employed when it burns the firebars.

The extraordinary purity of the Welsh anthracite will be obvious from the following characteristic chemical analysis. It is that of Stanllyd Vein, Blaina Colliery, Carmarthenshire, which contains 93·76 per cent. of fixed carbon, 5·09 per cent of volatile matter, 1·15 per cent. of ash, 0·75 per cent. of sulphur, and an inappreciable percentage of moisture.

The calorific value of a good anthracite is very high, attaining to a maximum of about 15,531 B.T.U.'s (8,624 calories), equivalent to an evaporative power of 16·06 lbs. of water.

This type of coal is in much greater request abroad, both on the Continent of Europe and in America, than in Great Britain. The beautifully clear atmosphere of the towns of New York, Boston, Chicago, Washington, etc., is due to its use. Consequently, the United States of America produces much more anthracite than we do—about seventy-one million tons per annum, as against six million tons for Great Britain, but whereas the tendency in point of its output is on the up-grade in Britain, it is on the down-grade in the United States. In the latter country in 1917 the output of anthracite was nearly eighty-nine million tons. Over sixty per cent. of the British-produced anthracite is exported.

SCIENTIFIC RESEARCH WORK ON COAL

Of late years there has been much scientific research work directed to determining the composition of coal and its decomposition. For investigating the coal substance, three experimental methods have been employed, namely (1) thermal decomposition, (2) what is termed "fractionation," or splitting up the coal substance into several parts by a sequence or combination of solvents, and (3) oxidation, hydrogenation, haliogenation, etc., of the coal.

Professor W. A. Bone, in his valuable work "The Constitution of Coal" (*Soc. Chem. Ind.*, June 19, 1925), draws attention to the fact that little importance appears to have been attached in recent coal research work to the nitrogenous constituents of coal, and he doubts the correctness of the application of the term "resinic" to certain constituents of coal. He has shown, at any rate in the case of immature or brown coal, when under thermal decomposition, that up to a certain temperature (375° C. in one case) the only gases expelled are steam and oxides of carbon, and that this continues right up to, and perhaps beyond, 700° C., and that at a somewhat higher temperature (375° to 500° C. in some cases) methane and other hydrocarbons, without oxygen, appear, and that the hydrogen does not appear among the products until the temperature exceeds 500° C.

In regard to the second method, the solvent action of pyridine on coal was discovered by Bedson in 1899, and Clark and Wheeler much later—namely, in 1913—"fractionated" coal substance into three parts by first dissolving with pyridine and then treating the extract with chloroform, so that the three substances obtained were: (*a*) That insoluble in pyridine; (*b*) that soluble in pyridine, but insoluble in chloroform; (*c*) that soluble in both pyridine and chloroform, and to these they gave the names of *Alpha, Beta,* and *Gamma* respectively. Some scientists object to this classification, as all three substances contain carbon, hydrogen, nitrogen, oxygen, and sulphur. Bone has employed benzene under pressure in his treatment of the coal, the pressure being between 500 and 700 pounds per square inch and the temperatures 260° to 285° C., and, fractionating the extract by a solvent treatment, he by this means obtained four distinct soluble fractions (*Proc. Roy. Soc.*, 105, Sec. A., 1924). He shows the results, diagrammatically, thus:

Concentrated Benzene Solution of Crude Extract poured into Light Petroleum (b.p. 40°-60°).

Soluble.		*Insoluble.*	
Benzene-free light petroleum.		Ethyl alcohol.	
Soluble.	*Insoluble.*	*Soluble.*	*Insoluble.*
Fraction 1.	*Fraction* 2.	*Fraction* 3.	*Fraction* 4.
Non-nitrogenous heavy oil.	Red brown solid; softening point about 25°C.	Non-nitrogenous brittle resinous red brown solid; softening point about 60°C.	Nitrogenous amorphorous brown solid; softening point 180°-230°C.

Commenting on these fractions, he states that fractions 1 and 2 could be disregarded from the point of view of containing substances of a "binding" character when working on a coking coal; as to fraction 3, the amount of this fraction was always very small, ranging between 0·3 and 0·8 per cent. only of the whole coal substance, so that, although it has good "binding" properties, and therefore would be to some extent a contributory factor, it cannot be considered as the chief cause of the coking properties of the coal. The substances contained in fraction 4 were rather of the "humic" type, differing from the so-called "resins," and constituted from 4·6 to 7 per cent. of the coal substance: and, as they have a very pronounced "binding" property, they probably constitute the chief coking factor in the coal. The benzene extracts from a brown coal are different from those yielded by a more mature coal, and as brown coals and lignites do not coke it would seem that the coking quality of a coal is the result of the maturing of the coal up to a point.

Finally, as to the third method. By subjecting coal to the influence of hydrogen under heat and pressure, the dream of the coal chemist has at last been realised in the partial liquefaction of coal, the hydrocarbons in the coal being saturated, and, it is claimed, some of the fixed carbon also. This has been achieved by the German chemist, Dr. Bergius. The process is still in the experimental stage, but should it eventually prove possible to work it profitably on a commercial scale, the results will be very far reaching, and possibly revolutionise the coal industry of the World.

CHAPTER V

THE RESOURCES, OUTPUT, AND CONSUMPTION OF COAL

The World resources of coal are immense, sufficient at the present rate of consumption to supply the World with coal for over 5,000 years, but the supply available in some individual coal owning countries will be exhausted long before then. For instance, at her existing rate of production, Great Britain has coal, down to a depth of 4,000 feet, only sufficient to last for 450 years. The resources of the United States of America will probably suffice for 2,000 years.

The coal resources of the World, both by continents and countries, were estimated, in terms of millions of metric tons (1 metric ton = 2,204·6 lbs.), by the Geological Congress held at Toronto in 1913, to be as given below, taking the minimum working thickness of a seam of coal at one foot, down to a depth of 4,000 feet, and between depths of 4,000 feet and 6,000 feet at two feet, the Congress regarding 6,000 feet as the limit in point of depth at which coal would be worked. Actually the greatest depth to which it has been worked so far is about 4,000 feet—namely, in Belgium, though in Great Britain it has been worked down to a depth of 3,600 feet (in Lancashire).

The World resources of continents in millions of metric tons are as follows:

Continent.	Anthracites, including Dry Steam Coals.	Bituminous Coal.	Sub bituminous Coal, Lignite, and Brown Coal.	Total.
Europe ...	54.346	693.162	36,682	784,190
Asia	407.637	760.098	111,851	1,279.586
Africa ...	11,662	45,123	1,054	57.839
America ...	22,542	2,271,080	2,811,906	5,105.528
Oceania ...	659	133,481	36,270	170,410
Total ...	496,846	3,902,944	2.997.763	7,397,553

Whether coal will ever be worked to a depth of 6,000 feet, or even 5,000 feet, is doubtful on account of two obstacles difficult to overcome—namely, heat and pressure. Not only does the temperature gradient vary considerably in different localities, but it is not easy to deduce a fixed law of increase applicable to all cases. In Great Britain the ratio of increase is about 1° F. for every 60 feet. The adverse effect of pressure is the crushing of the coal and the production of rock bursts (bumps) which are dangerous to life. The injurious effects of pressure have been felt in British mines at depths of even only 3,600 feet. It is doubtful whether there is much coal in the British Isles beyond 7,000 feet depth from the surface. The fact that metalliferous mining can be and is being carried on economically at a depth of 7,000 feet is no argument in favour of coal mining being carried on at that or even a much less depth; the conditions are entirely different. A normal vein or lode is, usually, highly inclined, but the coal seam being usually a flat deposit, or nearly so, renders the method of working and ventilation much more complicated, and the heat increment with increasing depth in coal mining strata is usually much greater than in the case of the strata in which mineral deposits occur.

The resources of coal in North America are stupendous, amounting to 5,073,431 millions of tons. Of all individual countries the United States of America holds first place, its resources being in excess of those of the whole of the British Empire put together.

It is frequently maintained that the period of coal supply may be and will be extended by the more economical use of fuel, due to the extension of our knowledge, enabling us to extirpate waste and make use of a much greater proportion than heretofore of the thermal value of coal, and also to utilise grades of inferior coal hitherto of no commercial value. Professor Jevons, however, maintained that it is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary he held was the truth, and such, in general, is the fact—the further any commodity is made to go, the cheaper an article is, the greater the eventual consumption of that article.

Of all kinds of coal the most important, at the present time, is that which we term—though incorrectly, seeing it contains no bitumen—bituminous, on account of its high volatile hydrocarbon content. Under this head are included gas making, coking, house, manufacturing, and nearly all the steam coals, and it is from the hydrocarbons of these coals that we obtain the by-products, tar, pitch, sulphate of ammonia, oils, benzene, toluene, dyes, and some medicines. It will be seen from the tabular statement given on page 40 that the resources of bituminous coal exceed those of the two other main classes of coal—that is, anthracite and the sub-bituminous coals.

The World output of coal of all kinds, including brown coal, lignite, etc., is on the up-grade on the average of years. Thus, whereas in 1903 the World production was 868,000,000 tons, in 1913 it was 1,342,300,000 tons, and in 1927 it was 1,450,000,000 tons.

The figures for 1913 are given as it was the last year before the Great War, and they are interesting on that account. Those of 1927 are quoted as being the latest figures available. It will be seen that in spite of the great disruption to industry and commerce created by the Great War, the World is producing, and presumably therefore consuming, about one hundred million tons of coal more than just before the war (when the industry and commerce of the World had attained a record—up to that time), and this in spite of the much greater economy practised in the use of coal and the encroachment of oil and hydro-electricity ("white" coal) on its domain.

THE COAL TRADE: BRITISH AND FOREIGN

The coal trade of Great Britain is the most important of all her industries with the exception of agriculture, there being directly employed in the production of coal in normal times no less than 1,110,884 persons (1913). It is, too, a very ancient industry—existing, we know, at the time of Henry III. of England—and probably long before—when he granted to the Goodmen of Newcastle-upon-Tyne the right to dig coals in the Castlegarth; and in 1245 mention is made of the ways of persons employed in getting coal. At Pittencrief, in Fifeshire, there was a coal mine in 1291; and in 1306 coal was introduced into London.

How great has been the growth and development of the coal trade of our country within comparatively recent years is realised when we compare the economical position of the present with that of the previous century. In 1811 the population of these islands was only 11,070,120, with a coal output (as estimated by the Royal Commission on Coal Supplies of 1871) of 10,080,300 tons, of which probably 9,735,082 tons were available for home consumption. In 1921, the last census, the population had quadrupled, being 47,123,000, and the output of coal by 1927 had risen about twenty-five times, being 255,417,600 tons, whilst that available for home consumption had risen nearly eighteen times, being 179,530,000 tons. It will be seen, therefore, that there has been a great increase in the consumption of coal per head of population; the comparative figures are 0·97 tons consumption per head of population in 1811, and 3·81 tons per head in 1927, the great augmentation being due to the advent of the industrial era, sometimes termed the "coal age," and the consequent advance in the standard of comfort enjoyed by humanity in civilised countries. Taking the year 1913 as the last pre-war year, and that of maximum output of coal in Great Britain, the figures for the five great coal producing countries of the World were as follows:

Apparent coal consumption per head of population in long tons (of 2,240 lbs.)

The United Kingdom	4·22
The United States of North America	4·98
Germany (including brown coal) ...	3·08
France	1·44
Belgium	3·44

If the coal consumption per head of population may be regarded as an index of commercial prosperity of a country—and if it is an indication of general output of commodities it may rightly be so regarded—then the United States is first and France last in the scale.

As was stated in the Report of the Electricity Sub-Committee of the Coal Conservation Committee, which reported in 1918:

> "It is obvious that improvement in the commercial prosperity of a country—that is to say, the average purchasing power of the individual—depends on increasing the output per head. If wages be raised merely by increasing the selling price of the goods in the home market, there is no real advance, and to increase the selling price of the goods in the neutral and open markets of the World, is hardly possible in view of international competition. The only way to increase prosperity is to increase the net output per head of the workers employed."

Would that our politicians and commercial magnates would take these words to heart instead of indulging in chimerical cures for trade depression. In the United States the power used per worker is fifty-six per cent. more than in Great Britain. The cure for low wages is more motive power.

The importance of the coal industry to Great Britain can hardly be overestimated. Again, taking the year 1913, as being the last pre-war year, Britain contributed 21·7 per cent. of the World's output of coal, and, including coal shipped as bunkers by vessels engaged in overseas trade, she exported 49·8 per cent. of her output, or 98·3 million tons. The comparative figures in respect of the three chief coal producing countries of the World—namely, Great Britain, Germany, and the United States of America—are as follows, the black coal equivalents being given in respect of brown coal, coke, and briquettes:

Country.	*Quantity in Millions of Tons.*		*Per Cent. of Total.*	
	1913.	1924.	1913.	1924.
Great Britain ..	98·3	82·0	49·8	51·2
Germany, including reparation deliveries.	47·4	25·1	24·0	15·6
U.S.A	23·6	19·8	12·0	12·4
Total of above ...	169·3	126·9	85·8	79·2
The World	197·3	160·2	100 0	100·0

It will be seen that Great Britain is the greatest coal exporting country in the World, though there has, of late years, been a heavy decline in that respect owing to a variety of causes, among which are the high price of coal, uncertainty due to the national stoppage of 1926, foreign markets not yet recovered, intensified development of the coal resources of other countries, and the increase in hydro-electric installations as well as, to some extent, the use of oil in substitution of coal for steam raising and the growth in the use of internal combustion engines. The coal exported (including bunkers)—the coal equivalents being given for coke and briquettes—during the year 1927 amounted to 71,779,530 millions of tons, or 28·6 per cent. of the output.

The consumption of coal in Great Britain, according to the latest figures available,* in point of percentage of total available for home purposes, is divisible as follows:

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* The figures are for the year 1925; those for the year 1926 are omitted as it was the year in which the national stoppage in the mining industry took place.

Consumed in gasworks	9·7%	or	16·45	million tons
Electricity generating stations	4·8	,,	8·08	,, ,,
Locomotives on public railways ...	7·9	,,	13·36	,, ,,
Vessels engaged in coastwise trade (bunkers) ...	0·7	,,	1·16	,, ,,
Ironworks (pig iron)	7·1	,,	12·03	,, ,,
Steel and ironworks (other than pig iron)	5·4	,,	9·26	approximately 86 to 91 million tons
Collieries (engine fuel)	9·1	,,	15 42	
Domestic (including miners' coal) ...	23·6	,,	40·00	
General manufacturing and other purposes	31·7	,,	53·81	
	100·0		169·57	
Quantity of coal exported			71·75	
			241·32	

Of the great industrial problems which call urgently for settlement, perhaps that of most moment is simplification in distribution, for when one compares, for instance, the cost of producing a ton of coal delivered into waggon at the "pit head" with the price at which the same coal is sold in, say, London, one is at a loss to understand the reason for the immense increase, for in such a case the selling price is often more than double the cost of "getting" the coal and putting it into waggons. It is frequently stated that the coal merchant makes too great a profit in the transaction, but it is doubtful whether that is so in the generality of cases. The trouble would seem to be in the complication of the system of distribution. In the home trade, in the majority of cases, the colliery company sells its coal at pithead prices to a merchant who bears the cost of transporting it to the distributing centre or centres, or this wholesale merchant, sometimes termed the "factor," disposes of his supplies to smaller merchants, and so on, each person dealing in the coal taking his profit. Eventually, the coal may be hawked about the town in small lots by persons owning a horse or two and a cart or two, and so the costs go up and up. Coal for export is, also, frequently sold through merchants, the latter undertaking the risk of chartering and unloading and reselling to customers. Some large colliery companies own their own vessels or have an interest in shipping firms. As to methods of payment, also, there is room for simplification. There is a great opening offered for a broad scheme of reorganisation in the distribution of coal. The amount of time lost in shunting and reassembling of waggons is very great, and the saving which could be effected in cross-country traffic is immense. The colliery owners by some system of combination or co-operative selling could achieve much. In their reorganisation they would have to keep in mind certain elementary facts. Firstly, that coal, in many instances, is being conveyed long distances by rail which might be consumed near the point of production; secondly, in view of the superior facilities afforded by the main trunk lines, the movement of traffic would be more expeditious and simple if it followed those routes; and thirdly, that it is desirable that, as far as possible, the movement of coal should be along well defined directions—that is, north to south, north to south-east, north to south-west, east to west. It was estimated, during the war, that a saving in transport of 700 million ton-miles would be secured by the transport scheme then in operation based on these lines.

The machinery in operation in the United States of America for the sale and distribution of coal is much the same as that operating in Great Britain. About fifty per cent. of the coal is marketed by the colliery companies, though they seldom sell directly to the consumer. There are some 1,500 wholesale coal merchants, exclusive of selling organisations of the purchasers, some 40,000 retailers (which is equivalent to one for every six or seven hundred families). It is estimated that sixty-one per cent. of the price of coal in the United States of America is due to transport and retailing.

In Germany, the colliery owners are bound by law to sell through district syndicates, the syndicates, which are not run to make a profit, determining the output quota of each colliery and fixing the selling prices, the coal being divided into classes—for example, gas coal, coking coal, steam coal, etc.—there being one price for each class. There are six such district syndicates in being in regard to black (stone) coal, and four in respect of the brown coal areas. All the syndicates are combined into the Reichskohlenverband, which has certain powers as to making laws and regulations for the control of the coal mining industry.

THE VALUE OF COAL AND THE COST OF PRODUCTION

What is the value of a ton of coal *in situ*—that is, ungotten and unsunk to—in the mine? This is a question often asked and not easy to answer. The correct reply would appear to be that it is practically valueless, for the pithead price of coal is made up of several concomitants—namely, rent, cost of production, and profit. Royalty rent is not rent in the true economic sense of the word, but a sale of coal, the average for the whole of Great Britain being in the neighbourhood of sixpence per ton. In Britain the coal is privately owned, whereas in some countries—for example, France—there is a system of State ownership.

The cost of production and, consequently, the selling price, varies greatly, the latter being governed by the two factors, cost of production and demand.

The purchase price of coal in the reign of Edward III., we know from an early record (*Pipe Rolls*, 40 Ed. III., 1367) reducing the mediaeval "chalder" to a tonnage weight, was about one shilling and five pence pen ton at a point not far distant from the point of production, but as money was then at least ten times its present value, the price in terms of present-day value would be 14s. 2d. The price in London was 4s. 11d., or in terms of present-day value, 49s. 4d., almost present-day figures. During the sixteenth century the price rose, the failure of the wood supply causing coal to be more extensively used than previously in the reign of Elizabeth, but towards the end of the seventeenth century and the early part of the eighteenth century we find that the price had greatly declined. About 1708 the unknown author of the *Compleat Collier*, the earliest textbook on collieries, lamented the low price of coal: "Was it ever heard or known," he writes, "that this Noble, the Main Coale, was sold, as lately as was, or now is, for 8s. per chaldron, water or Newcastle or Sunderland measure." A chaldron, now an obsolete measure, was equal to about one ton in weight in the reign of Henry V., 1421. In 1700 the Newcastle chaldron was declared to consist of fifty-three hundredweights, the original having been 2,000 pounds weight.

The price of coal in Great Britain has always varied considerably, being governed, like all other commodities, by the laws of supply and demand. Taking the prices ruling of late years, avoiding abnormal years, the average pithead price was 5s. 10d. per ton in 1896, 10s. 10d. per ton in 1900, 7s. 8d. per ton in

1903, 10s. 2d. per ton in 1913, 16s. 4d. per ton in 1925, and 14s. 7d. per ton in 1927. That is to say, the average selling price of coal at the pithead during the year 1927 was 43·4 per cent. above that of the last complete pre-war year.

The cost of producing coal (taking closely equivalent periods) in about 1901 (as based on Sir James Joicey's letter to *The Times*, May 22, 1901) was 6s. 3·01d. per ton, with a profit of 6·64d. per ton; in 1905 a fair average cost of working and putting coal into waggons was 6s. per ton; in 1913, as given in evidence before the Royal Coal Commission of 1919, it was 7s. 9d. per ton, with a profit of 2s. 5d. per ton; in 1918 the cost had more than doubled, being 18s. 6·34d. per ton; in 1922 (Mines Department figures) it was 18s. 1·6d. per ton, with a profit of 11s. 7d. per ton; and in 1927 (Mines Department figures) it was 14s. 10·2d. per ton, with a loss of 1s. 0·43 per ton. It will be seen that the cost of producing the coal in 1927 had increased by 91·5 per cent., as compared with the year 1913.

The period 1925 to 1929 was one of great depression, though there are signs of distinct improvement at the present time (March, 1929). The depression is not limited to Great Britain, but is worldwide.

THE CAPITAL VALUE OF THE BRITISH COAL MINING INDUSTRY

Efforts have from time to time been made towards ascertaining the capital value of the British coal mining industry. In the year 1907, the late Sir Robert Giffen and the present writer arrived at the formula of ten shillings per ton per annum as a basis for determining the then value of the industry, but fifteen shillings per ton would be nearer the present-day value, which agrees closely with the figure, given by Sir Joseph Stamp before the Royal Commission of 1919, of £135,000,000, based on the output of the five years preceding the war—not a very great figure in the light of modern finance. The capital value of the anthracite mining industry of the United States of America alone is valued at £198,000,000, and that of the soft (bituminous) coal collieries must be vastly greater.

CHAPTER VI

MODERN DEVELOPMENTS IN THE USE OF COAL

Writing as long ago as 1883, the late Mr. John Jameson of Newcastle-upon-Tyne, the inventor of an early type of by-product recovery oven for the manufacture of metallurgical coke, stated: "It seems safe . . . to predict that in the progress of science we are coming to a time when the use of raw coal for fuel will be looked upon as a barbarism of the past," but the prediction of forty-six years ago is still unfulfilled.

Taking an average bituminous coal as produced from the British coalfields, there is a loss in the burning of a ton of such coal, based on gaswork figures, of roughly ten gallons of tar, of ammonia equivalent to twenty pounds of sulphate, and of about 10,000 cubic feet of gas. These substances do not exist as such in the coal, for there is no ammonia in coal, either in the form of free ammonia or salts of ammonia, but there are combinations of other bodies containing nitrogen and hydrogen, and in the process of distillation a certain part of the nascent nitrogen unites, in conditions of extreme obscurity, with a certain portion of the nascent hydrogen to produce ammonia, and in the case of the hydrocarbons combinations take place to produce tar and gas.

The first record of the coking of coal is in 1590, when one, John Thornborough, Dean of York, took out a patent for purifying coal by coking it. In the seventeenth century coke was used to some extent for the drying of malt. Evelyn, in his delightful and instructive *Diary*, mentions witnessing on July 11, 1656, "Sir John Winters' new project of charring Sea Coale, to burne without the sulphure and render it sweete."

The aim and object of coking such coal as is possessed of coking qualities was, in the first instance, to drive off the sulphur to some extent, and, as Evelyn says, to render it "sweete" for domestic use; but before long the main use to which coke was put was in the smelting of iron, as, owing to the higher proportion of fixed carbon contained in coke as compared with bituminous coal, much greater heat was obtainable under forced draught with it than by burning coal. The object sought, therefore, in the manufacture of metallurgical coke is, firstly, to drive off all the hydrocarbons and, secondly, to obtain a hard compact fuel, for which purposes it is necessary that the coal should be treated under "high" temperature conditions—namely, carbonised at temperatures ranging from 1,100 to 1,300 degrees centigrade.

Metallurgical coke is made in ovens, closed chambers made of firebrick. The form in most common use during the last century was the so-called "beehive" oven, in which the heating was done by direct contact or by burning off the gases within the oven, the burning being regulated by air admitted through holes in the upper part of the door stopping. When the gas is burned off the glowing charge is cooled by jets of water thrown on it; afterwards it is drawn out through the door, breaking up into prisms or columns of coke with a semi-metallic lustre. The time taken to coke a charge of coal under these conditions is from forty-eight to seventy-two hours, the longer the heat is continued the denser being the product, but with a diminished yield owing to some of the coke itself burning. Under this system it will be seen that there occurs a great waste of valuable by-products, and the system has been in great measure replaced by the regenerative by-product recovery oven. There are still, however, in Great Britain, out of a total of 11,820 ovens, 1,808 beehive ovens in use. Of the 11,837,135 tons of metallurgical coke produced, no less than 11,110,035 tons are made in by-product recovery ovens. In the United States of America in 1926 no less than 56,865,537 tons of coke *of all kinds* (as against 24,201,140 tons in Great Britain) were produced, 12,488,951 tons of which were from beehive ovens and 44,376,586 from by-product ovens. Custom and prejudice die hard, and there are still iron-masters who are convinced that coke made in beehive ovens has both a physical and chemical superiority to that made in by-product ovens.

In the by-product recovery ovens, the ovens are heated by the gas evolved from the coal by passing it through flues surrounding the oven after it has passed through the condensing and scrubbing process by which the tar, ammonia, and light oils, etc., are recovered from it, the gas and air for combustion being separately distributed on each side and along the length of the oven and combustion taking place in each flue. Normally, from thirty-five to forty per cent. of the gas evolved is required for heating the ovens.

As indicating the nature and amount of the yield of the by-products recoverable under high temperature conditions, one may quote the results obtained with Durham coking coal. The yields, calculated upon the weight of dry coal carbonised, were 75 per cent. of coke, 3·85 per cent. of anhydrated tar, 0·93 per cent. of crude benzol, 0·56 per cent. of refined benzol, and 1·16 per cent of ammonium sulphate. From the tar, on redistillation, are obtained many important substances. It contains a small quantity of the paraffins, but is rich in naphthalene and anthracene; it contains, also, some benzene, toluene, and carbolic acid. It is from these tars that the well-known aniline dyes are obtained. The residue, pitch, is put to several uses, notably that of a binding material in the manufacture of briquettes (patent fuel).

Artificial Gas

An enormous amount of coke is made in *gasworks* under high temperature conditions. The amount of coal used for gas making at British gasworks being, in 1927, no less than 18,456,293 tons, resulting in 12,364,005 tons of coke. In the manufacture of coal gas the coke is in the nature of a by-product, and the carbonisation is very much the same as that in the by-product ovens, although the type of oven is different. The "gas coke," as it is commonly termed, is used as domestic fuel, for greenhouses, for the making of water gas, but rarely for raising steam. The amount of coke of all kinds made annually in the World at the present time is about 107 million tons.

The use to which gas distilled from coal might be put has for long been known. For instance, Dr. Clapton, of Kildare, in 1691, experimented with it, and may be said to have discovered gas lighting. Murdoch applied coal gas to lighting on a small scale in 1792, and Boulton and Watts' Engine Works at Birmingham were lighted up with coal gas in 1802 on the occasion of the Peace of Amiens; but the gas industry, as such, really started in 1812. A man of the name of Winsor had lighted a portion of Pall Mall by gas in 1807, and sometime thereafter formed a company, the Act incorporating the London and Westminster Chartered Gas Light and Coke Company being passed in 1810. The Company has continued in existence ever since, being one of the greatest gas concerns in Britain. The original project met with opposition, scepticism, and ridicule from scientists and other prominent persons. Even Sir Humphry Davy doubted the practicability of lighting towns with gas, and it was more or less ridiculed by Sir Walter Scott and the Great Napoleon.

The gas manufactured at gasworks, sometimes called *town gas,* is of two kinds—namely, coal gas which is distilled from coal, being that described above, and *water gas,* produced by passing steam through a bed of incandescent coke and so decomposing it into oxygen and hydrogen, the oxygen taking up carbon from the glowing coke, the resultant carbon monoxide with the hydrogen being known as *blue water gas,* as it burns with a blue flame. This, when enriched with oil gas to increase its luminosity, is termed *carburretted water gas,* which is distributed similarly as the coal gas.

The illuminating power of gas is reckoned in terms of candle power comparing its brightness, as exemplified by the gas jet burning five cubic feet of gas per hour, with that of the flame of a standard candle. Taking the cities of Leeds, London, Kilmarnock, and Paris, the composition of the gas producer will be found to be as follows:

Of Marsh Gas (CH_4)	from	32·30	to	42·80	per cent.
Of Olifines (C_6H_4) ...	,,	2·77	to	5·55	,, ,,
Of Hydrogen (H_2) ...	,,	39·11	to	52·80	,, ,,
Of Carbon Monoxide (CO)	,,	3·96	to	8·22	,, ,,
Of Nitrogen (N) ...	,,	2·70	to	8·00	,, ,,
Of Carbon dioxide and Oxygen (chiefly CO_2 with traces of O_2)	,,	0·00	to	5·35	,, ,,

Prior to 1917 it was generally assumed that the interests of the consumer of gas were adequately protected by the provisions of the Gas Acts which required that the gas supplied should be free from sulphuretted hydrogen, should be of a certain pressure when tested at a public lamp or the junction of a consumer's service pipe and the gas main, and that it should have an illuminating power when tested in a specified gas burner of so many "candles." Later, in some Acts, provisions were obtained substituting for a candle power test a test of calorific power of the gas, for the advent of the incandescent gas mantle, augmenting as it does the illuminating power of the gas, and the great growth in the use of gas for domestic heating and cooking purposes, rendered the heat value of more importance than the illuminating quality *per se.* In the year 1917, the Fuel Research Board* advised the general adoption of a new method of ascertaining the value of gas to the consumer—namely, the changing over from cubic feet to *therms.* By the method of steaming already mentioned—that is, passing steam through the vertical gas retorts—it was known that the heat energy of the coal obtained in the form of gas could be raised by twenty-five per cent., but under the restrictions of existing legislation had to be brought up to standard by enrichment with oil gas, as previously named, and likewise in the case of water gas. The Board, as the result of its investigations, formulated a scheme of charging by the "therm" instead of by the thousand cubic feet, a therm being 100,000 British Thermal Units, the gas meter still remaining for the purpose of measurement, for the product of the volume multiplied by the calorific value of the gas is the number of therms of a given gas. For example, 1,000 cubic feet of gas of a calorific value of 100 B.T.U.'s would be equal to a therm. This is now the basis adopted, the calorific value of the gas being continuously measured and recorded by a recording calorimeter of a standard type passed by the London Gas Referees.

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* At that time comprising the late Sir George Bielby, the Hon. Sir Charles Parsons, K.C.B., Mr. (now Sir) R. Threlfall, and Sir Richard Redmayne, K.C.B.

Thus, if we assume gas of 450 B.T.U.'s to cost 3s. 8d. per 1,000 cubic feet, the price would be 11d. per therm. It is interesting to compare the cost per therm of gas as compared with coal. A fair average price of good house coal, delivered into one's cellar in the neighbourhood of London at the present time, is about forty-five shillings per ton, the calorific value of which will be about 12,500 B.T.U.'s, so that the cost per therm is about 1·93d., say 2d., whereas the cost per therm in the case of gas is 9·4d., but in the case of coal there is much more loss of heat in the burning than there is in the case of gas, the composition of which is more perfect, besides which, there is the question of convenience. The fire can be turned on and off—not so in the case of a coal fire. It is these characteristics which render the use of gas for cooking in many cases as cheap as and preferable to the use of coal.

During the war, the gas industry, like the coal industry, played a great part, though those parts were different. The main source of the high explosives were the by-products of the gasworks. The total production of tar during the war was estimated to be 3,761,000 tons from gasworks, 36,000 tons from producer-gas plants, 2,236,000 tons from coke ovens, and 62,000 tons from water-gas plants, a total of 6,095,000 tons, of which amount about five million tons were distilled. Benzol, phenol, and toluene enter into the manufacture of various classes of high explosives, and these substances are produced in the distillation of coal and recoverable from the tar and gas.

The price of gas, like all else, has risen since pre-war days. The *average* cost in Great Britain was then about half-a-crown per 1,000 cubic feet, the extremes of variation being from about one to five shillings. The price will gradually come back to normality with the falling price of coal.

The decrease in the frequency and intensity of fogs in London and other great towns of Great Britain of late years is doubtless due to the considerable replacement of coal by gas as a fuel. This desirable result would be still further enhanced were the use of smoke-making fuels prohibited as domestic fuel in our large towns—that is to say, that where the use of solid fuel was desired, it should take the form of such smokeless fuel as anthracite or the semi-coke the result of *low temperature carbonisation*. The improvement could be brought about gradually and without undue hardship by limiting the compulsion, in the first instance, to households whose rateable value is above a certain figure, requiring them to take a certain proportion of their coal in the form of a smokeless fuel, gradually increasing the proportion and lowering the rateable value limitation. By such an enactment not only would the atmosphere of our great towns be vastly improved, and the inhabitants benefit in health and cleanliness, but a source of enormous wastage of valuable by-products would be prevented by the more scientific utilisation of fuel. It is just those coals which, on burning, emit most smoke which are richest in volatile hydrocarbons and, consequently, which best lend themselves to profitable treatment by low temperature carbonisation. Whereas anthracite, the use of which as a domestic fuel in Great Britain has developed greatly since the war, requires for its economic combustion special air feeding arrangements, "low temperature" semi-coke does not, for it can be burned satisfactorily in the open grate; the price, too, of anthracite is much higher than that of the semi-coke.

It is about twenty-three years ago since the idea of treating coal by partial coking at a temperature lower than that at which metallurgical and gas coke are made came into practical prominence, though some years before (in 1890) the late Mr. Parker had taken out a patent, and it was his process which came before the public for the manufacture of the much-discussed "Coalite," a process which is still in active being. Although the idea of producing a smokeless fuel had long occupied men's minds, whether by high or low temperature, to Mr. Parker must be given the credit of putting forward a definite low temperature process.

The outstanding advantages of carbonisation of coal under low temperature as compared with high temperature conditions are, firstly, that there results therefrom a fuel containing a small volatile hydrocarbon content, which on burning is smokeless and can be consumed in the open fire grate, emitting greater heat than a coal fire; and, secondly, that there are obtainable certain oils, of the paraffin group, as well as certain valuable tar acids to a greater extent than in the case of high temperature carbonisation. On the other hand, under only a very few of the low temperature carbonisation processes—and very many have been devised since Parker's day—is it possible to procure a coke which can be used suitably for smelting purposes, nor does it pay under low temperature conditions to recover the comparatively small amount of ammonia made which is such a valuable asset in high temperature carbonisation. The benzene, toluene, and other valuable substances, obtainable under high temperature conditions, either are not formed or are so in much less quantity under low temperature carbonisation.

Low temperature carbonisation may be said to range between 400° and 500° C., but, what the late Vivian B. Lewes used to call "medium temperature"—that is, ranging between 500° and 900° C.—is frequently regarded as low temperature carbonisation.

The crucial range of temperature in respect of low temperature carbonisation is between 400° and 500° C.

In the table below are given the yields of gas and tar from a good gas coal under a range of temperatures commencing at 400° C. and rising to 900° C. It will be seen that the lower the temperature the greater the yield of tar (tar oil) and the lower its specific gravity, but the higher the temperature the greater the yield of gas.

Temperature of Distillation.		*Volume of Gas*	*Yield of Tar.*	*Specific Gravity of Tar.*
°C.	°F.	Cu. Ft.	Galls.	
900	1,652	11,000	9	1·200
800	1,472	10,000	12	1·170
700	1,292	9,000	15	1·140
600	1,112	7,750	18	1·115
500	932	6,400	21	1·087
400	752	5,000	23	1·060

The low-temperature coal carbonisation industry, though much has been done in the direction of design and experiment in Great Britain, America, and Germany in particular, can hardly be said as yet to have achieved commercial success, though there is every reason to suppose it will do so in the very near future, and that a reasonable, though not a very high, return on the capital involved may be secured in respect of some of the processes at work.

As indicative of the yield of coke and by-products, results obtained at the Government Fuel Research Board's Station near Greenwich may be quoted. The coal in question, on analysis, was found to contain 0·95 per cent. of moisture, 31·43 per cent. of volatile matter, less moisture, 62·41 per cent. of fixed carbon, and 5·21 per cent. of ash. This shows it to be a high-class bituminous coal. The temperature of carbonisation was 600° C., and the derivatives were 15·58 hundredweights of semi-coke, 37·56 therms, 17·0 gallons of tar (dry), 26·4 gallons of liquor, 8·6 pounds of ammonia sulphate, and 1·63 gallons of motor spirit per ton of coal treated; also, the yield of gas was 3,440 cubic feet (1,090 B.T.U. per cubic foot), and the volatile matter in the coke was 11·81 per cent. Of 16·25 gallons of tar obtained from this coal, 9·35 gallons of various fractions of oils (which gave 5·578 gallons of washed and refined oils) and 2·74 gallons of tar acids

(2·34 gallons of washed and refined tar acids) and 75·9 pounds of pitch.

It has been estimated that were all the coal necessary for domestic heating in Great Britain to be used in the form of semi-coke, there would be available per annum in the manufacture thereof, two million tons of fuel oil for the Navy—which is considerably more than peace time requirements—and about 100 million gallons of motor spirit. To secure this, about ten million tons more coal would have to be raised annually, inasmuch as twenty hundredweight of raw coal produces only about thirteen hundredweight of domestic semi-coke.

PULVERISED COAL

The method of burning coal for the purpose of steam raising whereby nearly perfect combustion is secured is to use the coal in a finely divided state in an atmosphere of air affording a sufficiency of oxygen to ensure complete combustion, but no excess of air. The obviousness of this is evident when one considers that as a cubic inch of coal which has an exposed surface of six square inches, if crushed into one hundred equalised cubes, gives an exposed area of sixty square inches, and that a more intimate uniting of coal and air is achieved without resorting to an excess of air.

The dust is commonly used in a very fine state of division, so fine, indeed, that all of it will pass through a 100-mesh screen—that is, a screen containing 10,000 equally sized apertures to the square inch—and eighty-five per cent. of it through a 200-mesh screen. The dust mixed with air is burned in the form of a jet, the stream of coal dust and air usually being driven into the fire box by means of either a fan or compressed air.

Though coal dust firing has for some years been used in cement works, it has only recently been applied in Great Britain to steam raising, but it has been for long in vogue for that purpose in America. The reason for this is probably the fact that, until recently, the dust firing appliances were somewhat clumsy in design and inapplicable to stationary boilers of the Lancashire type. But, since 1920, not only in America, but in Britain, the development has been very rapid, so that the World's consumption of pulverised fuel to-day probably exceeds 150 million tons per annum. In the United States of America alone it is estimated that there are consumed annually:

In cement kilns	50	million	tons	of	pulverised	coal
In metallurgical furnaces ...	20	,,	,,	,,	,,	,,
In steam raising	30	,,	,,	,,	,,	,,

In some countries—for example, on the Brazilian Central Railway—locomotives are worked with pulverised coal. In the instance quoted, the coal is inferior in quality.

The advantages accruing from the use of pulverised coal are mainly: (*a*) A reduction in the quantity of fuel required by reason of more perfect combustion; (*b*) resort can be had to inferior and, consequently, cheaper qualities of fuel; (*c*) saving of labour in stoking and (*d*) flexibility of the operation of firing There are a number of systems of pulverised fuel firing. Those best known are the Quigley, Fuller, Lopulco, Buell, Woodeson, Peabody, Pre-gasification system (especially applicable to Lancashire boilers), and the Robinson, the last-named being applied to locomotives.

CHAPTER VII

NATURAL MINERAL OIL AND NATURAL GAS

That the occurrence of oil in the earth's crust was known to the ancients there can be little doubt. There are references to oil in the Bible as coming "out of the flinty rock," but from the context this would appear to mean the oil derived from olives growing in sterile regions. Herodotus mentions oil being drawn from a well at Kir-ab-ur-Susiana, "the oil they collect, and the Persians call it Rhadinance; it is black, and emits a strong odour." Strabo, Pliny, and others refer to the use of Sicilian oil for illuminating purposes. Plutarch, too, in his life of Alexander the Great, describes "a gulf of fire, which streamed continually as from an inexhaustible source," which much impressed Alexander, and, according to the late Sir Boverton Redwood, ancient Chinese and Japanese records contain numerous references to petroleum and natural gas having been employed as fuel and for illuminating purposes, centuries before the Christian era. The oil at Baku has for long been worked. Peter the Great, in 1723, had it collected and transported up the Volga, and in 1806 we find the deposits being systematically worked by Russia.

Natural oils, differing much in character and quality, occur in many parts of the World and constitute a very important source of fuel, both for raising steam and, more particularly, for use in internal combustion engines. The fuel oils range upwards from heavy fuel oil to petrol. There are also obtainable most of the oils used for lighting and lubrication. The chief oil producing countries are the United States of America, Canada, Mexico, Argentina, Peru, the Dutch East Indies, Trinidad, Persia, Burma, India, Russia, Rumania, Galicia, Japan, Egypt and Germany. Although oil has been tapped in Great Britain, it is so small in quantity as not to permit of its exploitation being regarded as a commercial proposition.

Natural oil, or petroleum, as it is commonly called, is chiefly composed of saturated hydrocarbons of the paraffin series (C_nH_{2n+2}) frequently containing solid paraffins dissolved therein. Members of the olefin series (C_nH_{2n}) are also associated therewith in greater or less quantity.

As to the *modus operandi* of the formation of petroleum, there is much controversy. The cosmic origin or postulate volcanic activity as the effective cause is usually regarded as being abandoned, though on the occasion of volcanic eruptions there is evident a considerable display of burning gases, and if one traces the course of the line of oil productivity over the World that line will be found to be roughly parallel with a line of volcanic activity past or present. Furthermore, petroleum is found to exist in early rock formations, the character of which and the comparative absence of organic matter therein would seem to preclude an organic origin to the oil.

But putting aside this view of the principal theories which hold the field at present, that which is the least popular is the inorganic theory that petroleum originated from the interaction of metallic carbides presumed to exist immediately below the earth's crust, whereby various hydrocarbons were formed which underwent further changes, including polymerisation, to produce the compounds which are found in petroleum, but against this otherwise plausible theory is the fact that there occur in natural oil certain optically active substances termed cholesterol and phytosterol, which are characteristic constituents of animal and plant matter respectively. Furthermore, nitrogen is found in some petroleums. But these facts do not seem to the present writer to conclusively rule out the inorganic theory of the origin of petroleum. It has yet to be proved that the optically active substances and nitrogen cannot exist naturally in inorganic substances, or, if not existent originally, be introduced from external sources. *Prima facie,* there seems to be no reason why bitumen should not be a primitive compound, engendered in the interior of the earth, like carbonic acid and nitrogen, the real origin of which is also unknown. The remaining, and the most generally accepted, theories attribute the presence of petroleum in the earth to the decomposition of organic matter, either animal or vegetable, but in such case there is some difficulty in accounting for the existence of petroleum in quantity in the older rocks—for example, the oil wells of Canada flow from Silurian and Devonian rocks, some of those in the United States of America from the Devonian. It is true that the majority of oil wells are sunk to much more recent formations. Many of the oil deposits of the United States are in the Carboniferous, those of Trinidad, as well as those of the Caspian and Persia, in the Tertiary. What was the process of metamorphosis of organic matter into mineral ore? There is no evidence of distillation in the immediate neighbourhood of the oil deposits of the newer formations. Then if not distillation, what was the process of transformation? The process of decay does not seem to afford a solution. Much more research work will have to be carried out before a satisfactory explanation is forthcoming.

The oil occurs, usually, in porous sandstones or limestones, and it would seem that it exists in pools or reservoirs separated from each other by impervious rocks. Sometimes the oil is pent up under pressure, and when struck bursts forth with great force, accompanied or preceded by natural gas, often ultimately to be followed by water, usually salt, which has, on the artesian well principle, lain behind it. Sometimes the salt water rises with the oil. But in a "gusher," as a high pressure well is termed, the oil flow need not necessarily be followed, eventually, by water, but the oil gradually lessens in flow, necessitating eventual pumping to raise it. It is estimated that, at most, twenty per cent. of the oil only in the ground is brought to the surface by present methods of recovery.

The natural oil resources of the World, as estimated by the Geological Survey of the United States of America, amount to 43,055 millions of barrels, of which U.S.A. accounts for 7,000 million, Persia and Mesopotamia 5,821, S. Russia, South-West Siberia, and the Caucasus 5,830, Mexico, 4,525, Northern South America 5,730, Southern South America 3,550, and the East Indies 3,015 barrels, the weight of oil being seven barrels to one ton.

Summarising the conclusions of the *Power Resources of the World (Potential and Developed)* the Official *Review* of the Fuel Congress held in London in 1928, published in 1929, states: "In the present state of oil production, where a few international combines dominate the market, it would be dangerous for a number of countries to disclose their oil resources, if they had any real knowledge of them, while experts to these great combines are surveying the entire World for oil possibilities. We can be sure, therefore, that any statistics that are published of oil resources are probably totally inaccurate and have their real basis in propaganda;" and the *Review* of that work recommends a survey of the oil and natural gas resources of the World be undertaken by the World Power Conference.

The total output of petroleum in metric tons per annum of the various mineral oil producing countries of the World was, for the years 1919 and 1927, 72,170,190 and 165,950,000 tons respectively. Of the present-day output the British Empire contributes only 1·5 per cent. and the United States of America 72·5 per cent. The World production of mineral oil has increased 130 per cent. in eight years, and the American output 138 per cent. At the present rate of output, and regarding the estimate of the resources as given by the United States Geological Survey as correct, the United States has only seven years' supply available. But the probability is that the estimate of the oil resources of the World "is subject to radical modification, as the technique of mining and of oil extraction changes and the distillation of the crude into more refined products becomes adapted to economic conditions and more complete technical knowledge."*

The petroleum as raised from the wells normally has to be refined before use—that is to say, be subjected to fractional distillation. The light fractions included under the heading "Naphthas" and variously termed petrol (English), benzine (German), and gasoline (American), come off at temperatures up to 150° C., and the illuminating oils at 150° to 300° C. The various oils are refined by washing and other methods. Only the heavy oils are used for burning as fuel for steam raising.

The important physical characteristics of an oil, besides its calorific value, are the *flash point* and the *viscosity*. The flash point is the temperature at which vapour is given off from the oil in sufficient quantity to be ignited by a flame. This, and the *ignition point*, or the temperature at which sufficient vapour is given off from the oil to continue burning, are of importance in regard to internal combustion engines, and in respect of lubricating oil, the flash point of which in the latter case should be low. Viscosity may be defined as the time which oil will take to flow through a given orifice in a certain apparatus at a given temperature. The bearing of viscosity in respect of the flow of oil used for burning to raise steam is obvious. A fuel oil should have a flash point of about 60° C., should be mobile, should contain not more than two per cent.

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* *Power Resources of the World (Potential and Developed)* issued by the World Power Conference.

of moisture or more than one per cent. of sulphur, and should have a calorific value of not less that 18,000 B.T.U.'s per pound. The British Admiralty requirements are, however, more particular and drastic than these, and the calorific value required is higher.

In the coal mines the existence of natural gas has been known for generations under the name of fire-damp, and occasionally has occurred in such quantity, in blowers, as to permit of its being used as fuel—for instance, a blower of gas was encountered at Jarrow Colliery, on the banks of the River Tyne, which caused a severe explosion in 1826 and continued to discharge gas for at least ten years afterwards; and at Wellington Colliery, in the same locality, a blower of gas was encountered in 1831, and the gas conducted by a three-inch pipe to the surface, where it burnt with a flame about three feet in height for years.

A large modern colliery in, say, the Yorkshire coalfield, will give off in twenty-four hours fully 700,000 cubic feet of marsh gas, but it is so diluted with air as not to be commercially recoverable.

Wells drilled for oil in the United States often produce gas and often do not; the gas frequently exists under pressure upwards to 900 pounds per square inch at first, gradually falling as the blower exhausts. Some of these wells yield an enormous quantity of gas. It is stated that at the Karg well, the boring of which was completed in January, 1886, fourteen million cubic feet of gas were wasted for months, no less than 1,500 million cubic feet having been lost before any was used, but the yield continued for nearly three years. The gas is composed chiefly of saturated hydrocarbons (CH_4), but there are present also small quantities of ethane (C_2H_6), unsaturated hydrocarbons and carbon monoxide (CO), and of hydrogen (H). As would be presumed from its composition, the calorific value of the gas is high, sometimes attaining up to 1,135 B.T.U.'s per cubic foot. Compression, which condenses some of the constituents, reduces its thermal value, but it is still high, about 840 to 900 B.T.U.'s. Per pound the calorific value works out at about 22,090 B.T.U.'s as compared with 14,000 B.T.U.'s in the case of a high-class steam coal, and 19,000 for a good fuel oil. It will be realised, therefore, that it constitutes a most desirable form of fuel. Natural gas was first put to industrial use at Pittsburg, U.S.A., in 1879, for puddling iron. An estimate of the natural gas resources of the World is, of course, impossible, but the annual production has been determined and amounts to about 1,360,000,000,000 cubic feet, or nearly four times the volume of gas yielded in making coke.

The chief producers of natural gas are :

U.S.A.	with	1,313,019,000,000	cubic	feet,	1926	figures
Canada	„	18,431,252,000	„	„	„	„
Poland	„	18,893,736,000	„	„	1925	„
Rumania	„	13,304,994,000	„	„	1926	„
Jugo-Slavia	„	3,000,000,000	„	„	„	„
Japan	„	802,000,000	„	„	„	„
Italy	„	209,770,000	„	„	„	„

CHAPTER VIII

THE PRODUCTION OF POWER AND FUEL IN THE FUTURE

Reference has been made frequently in the preceding pages to the use of fuel for the *production of power*. In this relation we have to regard fuel from the point of view of consumption per horse-power produced, into which consideration three factors enter—namely, the quality of the coal or other fuel, the completeness of its combustion, and if the contrivance for transmitting the power be a steam engine, the most economic use of the steam produced.

Coal or other fuel should be so burnt as to get the utmost value out of it. Once the inflammation temperature has been reached, it is the physical state of the combustible that mainly determines the rapidity with which combustion takes place; the greater the amount of surface exposed to the action of the air, the more rapid the combustion. An insufficient supply of air to the fire results in incomplete combustion, and all air over and above that required for complete combustion of the fuel acts as a cooling agent. Of course, the engineer has to regard the question of the consumption of fuel from the point of view of the cost of the horse-power produced. A high priced fuel may, judged from this aspect, give cheaper results than a lower priced fuel, or again, the lower priced fuel burnt in a certain way may afford a cheaper result than the higher priced fuel burnt in another or even in the same way.

Thirty or forty years ago it was customary to allow five pounds of average coal per horse-power per hour as good practice, though in some cases of bad practice it was as high as twenty pounds. It has been estimated (see Report of Coal Conservation Committee, Electricity Sub-Committee) that taking the whole of the coal consumed in industry in Great Britain at the beginning of the twentieth century (railways omitted), the average coal consumption per horse-power-hour would be about 10·7 pounds, or for power purposes alone, 8·03 pounds, and in 1917, five pounds, whereas the consumption of coal per horse-power-hour delivered at consumers' terminals, as burnt in the best possible way at Electricity Power Companies' Stations, would be only 1·54 pounds. The saving of coal that would be effected by the scientific burning of coal, therefore, is seen to be enormous. If railways are included, the saving that would result from the general application of electrical generation and transmission of energy for power purposes in Great Britain would amount to 56 million tons per annum.

The thermal efficiency of a boiler under ordinary practice may be put at about seventy per cent., though as high as eighty-five per cent. has been obtained under special conditions. The efficiency attained regarding boiler engine and everything combined as one price of plant—that is, as between the fuel and the power delivered by the engine—is usually from about ten to fifteen per cent. in an average plant working under steam, as against thirty to thirty-five per cent. in that of an internal combustion engine, but recently efficiencies as high as 21·5 have been obtained in cases where the boiler efficiency was eighty per cent. and the steam pressure 350 pounds per square inch. In another case where the boiler efficiency was eighty-five per cent. the total efficiency of the plant was twenty-three per cent. And it has been claimed that it is possible to obtain, with the steam turbine and a very high steam pressure, an efficiency of twenty-seven per cent.

Within recent years, too, the advantage of the utilisation of *exhaust steam* in turbines has been realised, but this method of saving fuel is capable of still wider application. It is, of course, well known that the amount of energy to be obtained from steam at low pressure is considerable, but the very large amount of energy in low pressure steam is not always realised. It is popularly supposed that if saturated steam is expanded from 200 pounds pressure per square inch to atmospheric pressure, the greater part of the energy has been obtained; but the energy liberated by the expansion of one pound of dry saturated steam from 200 pounds to fifteen pounds (atmospheric pressure) is 4,000 foot-pounds, whereas the energy liberated between atmospheric pressure and one-half pound absolute pressure is 8,000 pounds, or twice as much. The figures are, of course, theoretical, but if they are multiplied by an efficiency factor the ratio of the first to the second will not be greatly altered. It is this energy, about two-thirds of the whole energy in the original steam, which is being daily thrown away where non-condensing engines are in use.

It is probable that the use of *raw coal* in the open grate of our houses is doomed, eventually to be replaced by *smokeless solid fuel,* gas, or electric heaters, but in the first instance the most profitable application of low-temperature carbonisation of coal will be in conjunction with electric power stations where there exists on the spot a means of utilising the semi-coke and waste gas in the generation of steam; though to burn gas for raising power when it can be sold for illuminating and domestic heating is uneconomic. Gasworks, too, will probably adopt the low temperature carbonisation of coal for the generation of a part of their gas requirements, and will become large purveyors of smokeless fuel. In fact, it is possible that we may witness a gradual transference to the gas companies of the present activities of the coal merchants. The whole position of high and low temperature carbonisation of coal would be greatly simplified and aided were a practical solution found of the problem of how the surplus gas produced in the cokeries of the mines may be utilised in other parts of the country, particularly in the adjoining industrial districts. The solution will probably present itself in a scheme of *long-distance gas transmission* and of a gas authority purchasing all available supplies of gas at a fixed rate, something on the lines of the electric grid scheme and the Electricity Board, which is in process of being carried out in Britain at the present time. Though in Britain we have not so far practised long distance transmission of gas, it has been in operation in Germany for some years. For instance, to mention one case only, the Rhenish Westphalian Electricity Company has been working such a system for the past sixteen years, supplying thirty-eight localities over a distance of sixty-one miles, its pipe lines having a total length of 171 miles and delivering in the year 1926-1927 nearly 77 million cubic feet of gas. Were the coal owners enabled to have an interest in the production of gas it would go some way to compensating them for the cheap price of coal which benefits the gas and other industries; as it is, coal and its by-product, gas, are divorced in this country and coal owners are unable to offset an uneconomic price for raw coal forced on them by competition by profits from gas.

There is no doubt that the erection of *super-power electrical generating stations* at convenient spots through Great Britain will allow of a much cheaper electricity supply than is at present available, owing to the economic use of fuel and the provision of a high load factor but, owing to the former, the output of coal at first will tend to decrease, though, as the cheaper anything is the greater the eventual consumption, the coal output will, ultimately, be on an upward grade.

Of late years, oil has been taking the place of coal in ships, and of the ships at present under construction the majority are being designed to use oil for driving them, either for burning to raise steam or in internal combustion engines of the Diesel type. Yet there can be little doubt that the fuel of the future for ships is undoubtedly coal *if and when high pressure steam replaces the present practice of low pressure steam.* By high pressure steam is meant steam of a pressure of from 500 to 650 pounds per square inch. That this assertion has a sound basis has been shown by Sir John Biles.

Taking the price of coal at 24s. per ton and oil at 80s., the high efficiency of oil engines gives 1 S.H.P. for 4/10 of a pound of oil, and as one pound of oil costs 43/100 of a penny, one S.H.P. in a Diesel engine costs 17/100 of a penny. In an ordinary marine steam engine and boiler 1 S.H.P. requires 1·7 pounds of coal and costs 13/100 of a penny per pound, so

1 S.H.P. costs 22/100 of a penny against the oil produced S.H.P. at 17/100 of a penny. In the case of the *King George V.* (built in 1926 and using high pressure steam at between 500 and 600 pounds per square inch) this has been reduced to 14/100 of a penny, so that it has been demonstrated that coal is a cheaper fuel to produce a given power than oil in a Diesel engine. Besides which there is a lower relative first cost and less weight in respect of the steam engine as compared with the Diesel. With pulverised fuel a further considerable economy would be secured by reason of the more perfect consumption of the fuel as compared with lump coal, the reduction in the labour employed at the boilers, and the flexibility of the operation (coal dust firing in this respect being almost equal to oil firing) and other important benefits.

A probable and interesting development in the use of pulverised fuel is in connection with internal combustion engines, in regard to which experimental work is being conducted. Should a practical method be found for clearing away the fine ash from the exhaust, the commercial results would be very far reaching indeed.

Where the provision of oil is of importance, as, for instance, in the case of war, when the importation of oil is a difficulty, low temperature carbonisation may possibly, to some extent, replace high temperature carbonisation for making metallurgical coke. By the Plassmann Low Temperature process, for instance, it is possible to make a semi-coke robust enough to withstand the weight pressure to which it would be subjected in the blast furnace. The tar oil obtained by the low temperature distillation of coal can be used directly as liquid fuel—roughly it has a calorific value of about 17,000 B.T.U.'s—but this would seem a wasteful use to which to put it. These tars vary, of course, in quantity and to some extent in composition in accordance with the coal used and the temperature of treatment, but taking as an average example ordinary

British bituminous coal, with about thirty per cent. of volatile matter, one would expect to obtain between six and seven per cent. of waterless tar, say fourteen gallons, of which about from seventeen to twenty per cent. would be tar acids (phenols and cresols). About thirty-five per cent., or thereabouts, of the tar could be fractionated into about five gallons of light and heavy naphtha, burning oils, gas oil, and light lubricating oil. That is to say, five gallons per ton of coal treated. The tar acids are put to various uses—for example, as wood preservatives, insecticides, sheep dip, and so on. As to the future treatment of the oils, the important question is: Can they be commercially converted into lighter oils by "cracking," a process which is extensively applied to heavy natural petroleum oils? Briefly stated, "cracking" is a process under which oils, intermediate between the illuminating and lubricating oils, on the application of heat far above their boiling points, break down into lower boiling oils with, in the process, the formation of a certain amount of gas and of solid carbon. Dr. Gustav Egloff is quite definite upon the subject of the crackability of coal tars and their commercial conversion into motor fuel on a commercial basis and gives a number of instances. For example, a West Vergian coal retorted at low-temperature produced twenty-five gallons of tar which cracked under one hundred pounds pressure, and an average temperature of 452° C. gave a thirty per cent. yield of motor fuel, containing twenty-five per cent. of tar acids, or, on an acid free basis, a twenty-three per cent. yield. On cracking German lignite tar at ninety pounds pressure and 438° C., a "gasolene" yield on a tar acid and base free basis was thirty-eight per cent. of the oil treated, and a distillate oil from the tar gave a forty-seven per cent. yield of gasolene at 150 pounds pressure and a temperature of approximately 454°C.

If the process of cracking can be applied successfully, from the commercial point of view, to the oils obtained by the low temperature distillation of coal, this, added to the benzole obtained by stripping the gas, opens out a very wide field of usefulness to this method of treating coal.

The liquefaction of coal has been mentioned already on page 39. This process, first patented in Hanover in 1914, consists briefly in supplying to heated coal hydrogen under pressure. The temperature is between 400° and 500° C., and the pressure between 150 and 200 atmospheres. It would appear that the result of the treatment of ordinary bituminous coal by the Bergius process is to secure fifty per cent. of oil and pitch, twenty per cent. of gas, and a valueless residue composed of carbonaceous matter and ash. But in order to get this result, about another ton of coal is required for working the process, so that in the net result it is probable that not more than thirty per cent. of oil is forthcoming. The liquefaction of brown coal is being carried out at the Lenna Works of the I.G. Farbenindustrie, but little information is available as to how the work is proceeding, except the general statement that the initial difficulties are being overcome and the production of petrol is increasing and finding a ready sale.

In regard to the liquefaction of bituminous coal, an experimental plant has been erected at Duisburg-Meinderich, by the A. G. für Kohleveredelung, to treat some 30,000 tons of coal per annum by the Bergius-Billweiler process, from which it is expected to procure some 13,000 to 15,000 tons of marketable oils annually.

When the natural oil resources of the World are exhausted, which, probably, will be within eighty to one hundred years from now, we must look for our supplies of motor spirit to two possible sources—namely, the distillation of peat, brown coal, true coal, and oil shales, and to alcohol procurable from vegetable matter. It is twenty-four years since the Royal Commission on Coal Supplies stated in their final report, when considering possible substitutes for coal, that "alcohol is used in motors abroad to a considerable extent, but it is only as a substitute for oil that its use is suggested. As a fuel, it would not replace any large amount of coal." But it is probable that alcohol will some day take the place of petrol as the liquid motor fuel of commerce, and that day may be nearer than many suppose.

Reference has already been made to the light oils and benzole obtainable from the distillation of coal, and it has been estimated that from the gas produced by coke ovens in Great Britain at present engaged in benzole recovery, 30,000,000 gallons of pure alcohol could be obtained. Ethylene (C_2H_4) exists in coke oven gas and can be absorbed by charcoal. If this gas be washed and purified of sulphuretted hydrogen (H_2S), dried with concentrated sulphuric acid and the resulting ethyl-hydrogen sulphate subjected to hydrolysis and distillation in steam, weak alcohol is obtained. The commercial success of such a process, however, is yet to be determined. At present the cost of producing alcohol stands in the way of its extensive use as a commercial fuel, though it is used to some extent as such in Germany, France, and the United States of America. Its low degree of volatility and comparatively high flash point and the freedom from objectionable odour of the exhaust gases, render alcohol a useful and desirable fuel for automobiles.

It has been estimated that it should be possible to grow maize and cassava in certain tropical countries at as low a price as two pounds per ton, and that, with a rotation of crops consisting chiefly of maize, cassava, and sugar-cane, the cost of raw material for one gallon of alcohol should not, on an average, exceed sixpence, which would mean a retail price of approximately three shillings per gallon. The probability is that in process of time, better design and the advance of research will point the way to improvement in regard to crops and economies in manufacture which will reduce the cost of production of power alcohol. It is in tropical countries that the material best suited for the manufacture of alcohol is most abundant and cheapest, and wood scrub and refuse from the crops must annually constitute the main fuel supply.

As to the efficiency of power alcohol, numerous tests carried out by Mr. R. M. Sling, of the U.S.A. Geological Survey in 1907, 1908, and 1912, gave very good results. Thus, when the compression pressures were the same (seventy pounds per square inch) it was found that alcohol gave ten per cent. more power than petrol under the same conditions, and when the compression pressure of the alcohol engine was raised to 180 pounds, the maximum available horse-power was thirty per cent. greater than for petrol at seventy pounds compression. Unfortunately the use of alcohol is attended with corrosive effects, largely due, it is considered, to the esters in the wood naphtha used as a denaturant.

During periods of depression in the fuel industry, whether of coal or oil, a remedy is frequently sought in the form of restriction of output. But such artificial means have been tried in the past, have failed and are doomed to failure again. "Regulation of the vend," as it was termed, was tried as far back as 1605 in the coal trade of the North of England, and continued in various states of imperfection, though subject to intervals of freedom, until 1845. It failed then, but has reappeared recently in another form. The latest effort is witnessed in the oil industry. An endeavour is being made to restrict output. The *immediate* effect of such movements, if successful in achieving the end sought, can only be to force up prices, the *ultimate* effect, to induce consumers to resort to substitutes. The true cure for depression is cheapness in production and scientific utilisation of the commodity produced. For instance, the more efficiently coal is used the greater the ultimate consumption. The demand for commodities such as coal and oil is largely governed by the price at which they can be made available. Coal is in competition with fuel oil and hydro-electric power, and the World will purchase as much fuel in the form of coal as is economically justifiable. Restriction to meet a gradually diminishing demand must end in economic chaos.

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THE POLAR REGIONS

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LONDON: ERNEST BENN LIMITED
BOUVERIE HOUSE, FLEET ST. E.C.

First published 1930

MADE AND PRINTED IN GREAT BRITAIN BY
BILLING AND SONS, LTD., GUILDFORD AND ESHER

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THE POLAR REGIONS

CHAPTER I

INTRODUCTORY

Greatest of Heaven's lights, grandest of earthly sights,
Cape, island, shore,
Limitless plains of snow, peak, boulder, berg and floe,
Lit with thy radiant glow,
Greet thee once more.

"The Return of the Sun" *South Polar Times*

SPEAKING plainly and without prejudice, the world is interested in the polar regions. It may say scornful things about those remote places—that they are of little value, that they are chilly and forbidding—but it is interested, nevertheless. Ever and anon it is surprised into an open avowal of that interest by some tale of victory or of hardship or even of tragedy.

Scattered about the world there are a few people—hardly more than a thousand in all, perhaps—who have been to the polar regions, and a still smaller number who have spent a winter there. There is nothing to mark these people out from others, unless it be a shade greater robustness and a trifle more eagerness for adventure. For the most part, they are apt to be reticent, but it is with these people that we want to talk, to hear what they saw and did in that short span of their lives when they were polar explorers.

Years ago there used to be a convention among sailormen that those who had sailed round Cape Horn were allowed to put one foot on the table after dinner, but those who had crossed one of the polar circles were allowed to put both feet on the table. It will be our object in this book to try and find out what it is these gentlemen with both feet on the table would talk about when they are in reminiscent mood, to picture through their eyes what it all looks like, and to catch what we may of their feelings when they stalked bears or hauled sledges or butted their way through the pack ice. For of books on the polar regions there are many, but of intimate talks there are few, in print. At the end of this book there is a list of publications, which are either narratives of special expeditions or are treatises of the textbook type. This account of the polar regions is neither, but is an attempt to see them through the eyes of those who have been there.

But first of all a word or two about these people who are allowed this privilege of two feet on the table, and who so rarely take advantage of it, who, in fact, are rather apt to grow silent when they are pressed too hard to talk about their experiences. Most of them are of those who go down to the sea in ships and have done their business in great waters, and it is well known that they are usually somewhat inarticulate and find difficulty in telling what they have seen of the works of the Lord or in describing the wonders of the deep. Others, again, are scientists, and not a few of them can only be described as men of leisure—that is to say, men who could choose a life of ease were they so minded, but seem to prefer to scorn delights and live laborious days in travel. In a word, they are an odd lot, for we must not forget that they include ne'er-do-wells and occasionally a charlatan or two. But they have one or two things in common which it will be as well to mention. Practically one and all are ready to return to the polar regions for another visit, which in itself shows that there is something about the parts beyond the circles which is better than the public imagines. Then, again, there is in all of them something of the boy, as though they had never quite grown up, something which makes them look upon strange food and foul weather and hard work and frozen fingers as rather a "lark," something which tends to give them a far-away, visionary look, as though they were always living just a little bit in the past in strange scenes of a vast solitude. Finally, for a third common quality, there is in all of them a spirit of comradeship which is all too rare in a competitive world, which, in fact, can only come from having lived with their fellows under conditions which called for a large measure of unselfishness and good temper, and which showed a man as he really was, quite stripped of any veneer or superficial polish. He himself may have failed in that test—for many do—but he will at least have seen what good comradeship means and have seen into his fellows' hearts to learn what he may be capable of learning of the naked qualities of a man.

Lest this should convey a false impression of these men, it must be added that, as in the rest of the world, there is a proportion of failures and of weak characters and even an occasional mountebank. Moreover, though they may have been fine characters beyond civilization, they are apt to be only too human when they return to it and fall victims to temptations of fame or money, to succumb to adulation, and to suffer from a superiority complex for a time. In other words, the polar explorer is not held up as a model in any sense, but he has tales to tell were he but articulate, and it is our business to put these tales together.

The first thing to understand about the polar regions is that their limits do not coincide with the polar circles, nor is it possible for us to draw a line on our maps to limit them, since they change with time, with our knowledge of them, and with our methods of travelling over them. To Pytheas, the Massilian, who first sailed to the Far North three centuries before the Christian Era, the polar regions began at the Orkneys, and, though he never reached the Circle and never saw the "congealed sea" of which he wrote, he must always rank as the first of that band of polar travellers who have adventured themselves and their fortunes to inquire what lay beyond the farthest known. A thousand and more years later, Othere, that stout Norseman whom the genial King Alfred persuaded to talk of his travels, sailed into the Arctic Ocean and found the White Sea. For him the Circle was, perhaps, the limit to the polar regions, but ever since his time in Scandinavia the scenes of his exploration have been known to be much less polar than Labrador, which is far outside the Circle.

In the Southern Hemisphere there is still less coincidence between the theoretical and the actual polar regions. If we take for the moment the region of floating ice as a practical boundary, we shall find it is nearly everywhere at least ten degrees, or 600 miles, outside the Antarctic Circle.

The actual proportion of the globe within the polar circles is not quite one-tenth of the surface, but polar conditions, in the ordinary sense of the word, reign over a great deal wider proportion than that. Nor can we take the limit of habitability as a boundary to polar regions, for the Lapps and Finns, the Samoyedes and Chukchis and the Eskimo have lived for many centories under conditions which even the hardiest must confess are truly polar. Other limits have been taken, such as that of trees or a certain arbitrary isotherm, without arriving at any very satisfactory boundary, so we will be content with a somewhat elastic one.

There are certain features about these regions which set them apart from other portions of the globe, and, though many of them are very obvious, it will be as well to run over them briefly, for they are fundamental to life there, and they introduce factors into one's ordinary habits which are not easily foreseen.

To begin with, once across the polar circles, the disconcerting behaviour of the sun strikes the traveller at once as something he must allow for in his mode of life. Indeed, with a little imagination even the tourist who travels north in a liner to see the midnight sun can understand that there is something a little awesome in this twenty-four-hour day, and something still more so in the twenty-four-hour night which will happen six months later. And as one goes farther north the days and the nights increase rapidly in length until, even in a very accessible place such as Spitsbergen, one has a day of four months' duration in the summer and a corresponding period of four months in the winter when the sun does no more to cheer the polar dweller than to throw a faint glow in the south round about twelve noon. This complete circling of the heavens by the sun has always attracted the attention of those who were accustomed to a more normal division of the hours of light and darkness. Pytheas himself, perhaps the first astronomer of his day, and well able to calculate what length of day a given latitude would give, was greatly interested in the matter, and asked the inhabitants of Thule to point out to him where the sun set on the longest day, for he never reached as far as the Arctic Circle itself. And the awe of the long hours of winter darkness grew no less as men pushed farther north, notwithstanding the fact that the reasons for them were well understood. Indeed, knowing that should they stay too long in the north they would be overtaken by continual darkness, men cut their Arctic visits as short as possible and never stayed later than September.

Nevertheless, the change from continual darkness to continual light takes sufficient time to allow one's mental and bodily habits to accommodate themselves to the unusual conditions, so that expeditions no longer look upon the coming of winter as a time of mental trial when everything possible must be done to occupy the minds and preserve the health of the members. In the great Arctic expeditions of last century special arrangements for variety in diet, for the provision of amusement, for regularity of exercise, and so on, were made, and these were useful in their way; but it has now been shown that the real preventative of polar ennui is work, and plenty of it. So the long polar night, formerly so dreaded, has now been recognized as irksome only to those who lack interest in their work and who therefore allow themselves to imagine terrors which do not exist. The only effect of four months' darkness on an active expedition is that, when the sun does finally skim the horizon and allow the men to see each other by natural light, they find themselves strangely wan as to their complexions, but otherwise very little different to what they were at the end of the previous summer.

Closely connected with the seasonal peculiarities are those more theoretical anomalies which, though of constant interest to the navigator, will only occasionally affect the layman. The convergence of the meridians towards the poles means much more than merely a rapid change in longitude in east and west journeys, and the final vanishing of all longitude at the pole itself. It means that the navigator, whether by land or by sea or by air, must keep a very careful account of time as shown by his chronometer, for it becomes almost his sole measure of longitude. This is not so difficult in an aeroplane, where the journey is limited to hours, nor too troublesome in a ship, where not only are the facilities for looking after chronometers good, but where the dead-reckoning given by records of distance run and direction steered serves as a check on the astronomical determinations. But on land by sledge party the chronometer problem becomes a very real one. There are some very famous instances of this difficulty which will prove the point. When Dr. Nansen and his companion Johannsen were making their fifteen months' journey over the polar pack ice they had the misfortune to forget to wind their chronometers, so that there was an uncertainty of half an hour or so as to the true Greenwich time. When they finally landed on an island in the Franz Josef archipelago they had no means of telling which land they were on, for, as far as their astronomical sights could go, they might have been on Spitsbergen within a short distance of habitations and plenty; indeed, it was long before they quite decided they were not there. Nor is it at all easy, in all the changes and chances of sledging, to remember to wind the chronometer watches every night. In Captain Scott's last expedition there were five chronometers taken on the pole journey, yet every one of these was at some time or another forgotten by the owner and allowed to run down, notwithstanding the fact that every night the routine of shouting "Wind watches!" was passed from tent to tent. In this case, however, since they did not all run down at the same time, and also because they were usually within sight of landmarks, the damage was not vital.

The importance of time is still better illustrated if we imagine two mishaps which might have happened to Peary when in 1909 he camped at the North Pole. If he had had a bad storm which obliterated his outward track, and at the same time his chronometer had run down, he would have been completely lost, for at that spot it is noon all day long and every direction is south. In actual fact, his compass would have saved him, and ineffective as the instrument is there his knowledge of the variation would have told him within a few degrees which way he should steer for his return march, and he would at least have aimed in the direction of America rather than of Asia. It will be understood, therefore, that the careful building of cairns to mark the route by Scott, Shackleton, and Amundsen was no idle fancy, but very necessary, both for navigation and as a guide to their food depôts. The niceties of navigation in these regions is, perhaps, too technical a subject for further reference, but two incidents in one of the Antarctic journeys will enable even the layman to appreciate their importance. On his first great journey on the plateau of the continent, Captain Scott had the misfortune to have his nautical almanac tables blown away in a blizzard. Since he was going far out of sight of any landmarks, this loss was almost enough to completely prohibit his journey. In the end he remembered enough about the position of the sun at certain recent dates to construct a curve in his notebook, from which he could extract the value he wanted with sufficient accuracy to make his navigation merely hazardous instead of foolhardy. On the same journey he had to describe the course to be steered by compass to a supporting party which was being sent back, and, since they were then on the line between the magnetic and the true poles, all he had to say to the leader was: "Your proper course is due east, so steer due west by the compass."

As if to make up for these difficulties of navigating in the polar regions when out of sight of land, Nature has arranged that, when within sight of land, it shall be seen at a great distance, either by mirage or because of the excessive clearness of the atmosphere. This characteristic of the regions is one which has hardly received its proper attention, partly because in the better known parts, at the fringe of ice and sea, the frequency of fogs gives quite a contrary impression, and it is only when far away from the fog zone that the visibility reaches its maximum, to a degree which is truly astonishing. It is due, of course, to the almost complete absence of dust in the atmosphere as well as to an extremely low humidity, so that the haze with which one usually expects distant hills to be pleasantly shrouded is entirely absent. Briefly, it means that whatever is large enough to make an impression on the retina will be seen quite clearly, and a ship, for instance, will not disappear because it is hidden in mistiness, but because it is so far away that its image is too small to affect the sight mechanism in our eyes.

For instance, it can easily be calculated at what distance a mountain of a given height should be visible above the horizon, but under ordinary conditions the actual mountain is very rarely seen at this theoretical distance because it is hidden by the haze. In the polar regions one can almost depend on seeing any mountain as soon as it is above the horizon. Thus, Mount Erebus, in the Antarctic, which should be visible for 132 miles, was actually seen at 140 miles, the extra distance being due to refraction. Another striking instance of this extreme visibility is that during an ascent of Mount Erebus a party was somewhat astonished to see on the horizon to the north a mountain which did not fit in with the position of any known island. It was seen with the naked eye, but, to settle the problem of what it could be, the theodolite was set up so as to magnify it. It was then recognized as a large mountain nearly 300 miles away. There are, of course, many mountains in the world which are theoretically visible at that distance with the naked eye, but, except under very exceptional circumstances, the dust in the air over that distance would render it quite invisible.

The clearness of the atmosphere, together with the absence of familiar objects such as trees and houses, is responsible for making it almost impossible to judge distance with any pretence to accuracy, and this fact leads to extraordinary errors, which, fortunately, are usually more amusing than serious. It is not unusual for men who have just reached a new locality so to under-estimate distance that they will start off light-heartedly for an afternoon walk to a feature which may be thirty miles away instead of the three or four which they presumed it to be. A more exasperating instance of the futility of attempting to judge distance is that of a sledge party travelling up a wide glacier in the Antarctic. At 6.30 p.m. the sledge party, somewhat tired after the heavy day up the glacier, were much relieved to hear the leader say that camp would be pitched by a solitary moraine boulder which appeared to be about half a mile ahead. The march went on, but the boulder did not seem to get any closer. At 9.30 p.m. a very tired party camped, still far from their goal, for, instead of being an ordinary boulder not far away, it turned out next day that it was as large as a house and had been many miles away when first seen. In the Arctic this difficulty in estimating how far off an object may be is not quite so pronounced, for on the sea ice over which most of the longer journeys have been made there is always a series of old hummocks and pressure ridges, which do not vary very widely in their dimensions, and these form an approximate scale by which to judge the distance of any object.

It is precisely this unfamiliarity with the object whose dimensions are being judged which is responsible for the great exaggeration in the reports about the size of icebergs. None have ever been measured as much over 300 feet in height, but they have been frequently reported by careful observers as 1,000 and even 2,000 feet high. Such false estimates would hardly be made over the height of an island in temperate regions, where houses or animals or trees form some scale to assist the judgment. Nor is it a matter of personal idiosyncrasy, for a whole ship's company may be as much at fault as one man, as when a ship discovered a large harbour, landed men on its shores, and took photographs and made a rough map. Ten years later a sledge party entered the same harbour over the sea ice and discovered, to their great surprise, that it contained a large glacier tongue right down its middle, seven miles long, a mile broad, and up to 100 feet in height, which did not appear in the reports or the map of the original discoverers. The mystery was cleared up when the original photographs were examined, for there was the glacier tongue as large as life, but it had been taken by the first men to see it as hummocky ice only a mile or so from the ship, instead of a much vaster mass some five miles away.

If there is this uncertainty as to the nature and size of objects in the polar regions when the weather is clear, it can easily be imagined that the eyesight and judgment can be completely at fault when either thick weather or heavy mirage comes to distort the appearance of things. For the sledger anxious to get ahead there is nothing so exasperating as a spell of overcast weather, when the sun casts no shadow and there is not even a horizon to divide snow from sky. In such case, there is nothing but a dull whiteness which is quite formless and in which one may walk into a snow wall or a pit without having the slightest warning. The sensation is far more eerie than in a dense fog, for the air is clear enough, yet there is no tone or shadow to guide one as to the shape of what is ahead.

In a normal climate we are accustomed to expect a certain drabness, a general diminishing in colour contrast when the sky becomes overcast, but in the polar regions this effect is not merely doubled, but takes on an almost minatory character. This is, perhaps, to be expected, since the landscape consists of a universal whiteness of ice and snow with an occasional contrast of dark land. The white is not a true white, for in sunshine every shadow has something of blue and something of lavender in it; the varying intensity of shadows alone provides the colour tone, and where the sunlight is truly refracted we have the most brilliant emeralds. But when direct sunlight is hidden by heavy clouds all colour disappears and the white becomes a drab grey, while the dark rocks and the sea become, if possible, blacker than ever. Nothing can be more beautiful than a calm, sunny day in the pack ice, but the oncoming of a few heavy clouds will turn a world of splendid colour into a scene of deadly monotony, if not of threat. The absence of a horizon in such weather brings out some curious psychological effects; thus, if men are pulling a sledge over perfectly level ice, they will invariably have the notion that they are pulling uphill. Indeed, the false horizon, which everyone is forced to imagine on such an occasion, always seems to be many degrees above the true horizon. On one occasion a party on the Great Ross Barrier, a sheet of ice and snow which is perfectly flat, was endeavouring to locate a food depôt which was marked by a small black flag on a mound of snow. It was an overcast day, and, having run down their distance, the party was considerably perturbed at not seeing the flag, which should have been within half a mile of them. Finally, after considerable searching, one of the party suddenly called out: "Ah, there is the flag! But what has happened? It is downhill." And one and all of the members felt that they were indeed looking downhill when they, too, saw the depôt flag. What had happened, of course, was that they had all adopted a false horizon far above the true horizon and had swept that with their eyes and telescope, so that when it at last was discovered on the true horizon they all felt that it was downhill.

It must be remembered, too, that in a region where nearly all objects are strange and irregular in contour a very small distortion, either by the light or by the distance, of the object may lead to extraordinary illusions. Perhaps the most striking instance of this occurred to Captain Scott on one of his minor journeys. It was, as usual, a grey day when there was no horizon and practically no shadows to show up the surface irregularities; the party was having a meal in the tent, and, looking out of the circular tent door, one man declared that he saw the dog teams approaching. There was considerable excitement, as no teams were supposed to be within many miles of this spot; but each member, on looking out of the door, descried two galloping teams which appeared to be some two or three miles away. The meal was prolonged to wait for the teams to arrive, but each time the men looked out of the door the teams seemed to be the same distance away, so that finally one member of the party got out of the tent and at once declared that he could not see any dog teams at all. After considerable puzzling and experiment it was found that the two dog teams some miles away were nothing but two little strips of black paper from a film-pack, fluttering in the wind a few yards from the tent door.

Mirage is not confined, of course, to the polar regions, but it can be just as illusory as the traditional mirage of the desert. William Scoresby, the great whaler-scientist, made many special observations of mirage, and has wonderful illustrations of the effects seen. But every polar traveller who has experienced calm, bright days will have seen much the same thing. Ships turned upside down, and above that another image right side up; icebergs which shimmer and flutter finally into the air, looking like giant butterflies; coastlines ,which appear and disappear in a moment, are all common features of such weather. Moreover, the traveller has only to be anxious to see some special object, just as the thirsty traveller in the desert imagines his oasis, and sooner or later he will find in the mirage what he is looking for. A party waiting to be picked up by a ship had many false alarms when icebergs or even shadows had for a moment taken the form of their ship, but one day a reliable observer, well above the sea-level, shouted "Sail ho!" and described the ship as only about five miles off, as bracing round the yards, and as flying a flag. After so many false alarms it was thought best to set up the theodolite telescope to confirm what was apparent enough to the naked eye, but this told the same story. Preparations to pack the sledges were begun when one member, who had climbed up rather higher, stated his doubts, and finally, when a cloud crossed the sun, the beautiful ship disappeared, or, rather, it turned into one somnolent seal about half a mile out on the sea ice.

The most familiar attribute of the polar regions is the extreme cold, but here again popular imagination is often led astray. The discomfort and the danger from the cold is not due to its intensity so much as to its persistence and the lack of ready means with which to counteract it. Every winter in Canada, Russia, and even in Scandinavia the temperature will fall to figures far below zero which are comparable with those recorded in polar regions. But the periods of such cold are apt to be short by comparison, and, moreover, the land being more or less inhabited, there are houses to take shelter in and wood for heating, which at least temper the cold and render it possible to get comfort at night. Within the polar circles, however, such low temperatures are the rule rather than the exception for the greater part of the year, nor are there any other means of getting warm except those which men can carry with them.

The lesson which some centuries of polar exploration have at last taught the traveller is a simple one, long known to the Eskimo. The only really satisfactory form of warmth is that derived from within the body itself, and, when suitably fed and clothed, the body will generate enough heat by itself to cope with all ordinary conditions. To men bred in temperate climates, where the onset of cold is met less by a change of clothing than by resort to fires or other external means of warming, it was, perhaps, natural to seek warmth in the North by some such means, and the long tale of disaster in the Arctic owes not a few of its chapters to this dependence on external sources instead of on a careful study of the problem of clothing to meet the conditions by conserving the body heat.

The lowest temperatures ever recorded come, strangely enough, from a place which is only just within the Arctic Circle—Verkhoyansk, in Siberia, which is comparable in latitude with the Lofoten Islands, off Norway, where sea ice is almost unknown. But if we are to seek the cold which is really the most prolonged and therefore most severe, we must go to the high plateau of Greenland or of the Antarctic. There we should find that for at least nine months out of the twelve the temperature would be generally below minus 30° Fahrenheit, there would be long periods below minus 50°, and occasional calm periods when the alcohol thermometer (mercury freezing at minus 40°) sank to the vicinity of minus 80°. These figures sound truly dreadful to those who are apt to shiver and seek the warmth of house fires as soon as the thermometer approaches the freezing-point, and it is somewhat difficult to persuade such people that there is a peculiar quality in extreme cold which renders it less dreadful than imagination pictures. It is, for instance, a dry cold, and, as such, less searching than our damp chilliness; and it is invigorating. It is certainly sudden in its onslaught on the finger-tips and rather alarming when it reaches the stage of producing deep frostbites, but when precautions are taken there are none of the long fits of shivering to which we are prone in this climate. In fact, it is so cold that one must either take rapid steps to get warm again or else the temperature will soon cease to be of interest.

Actually the thermometer is not the best means of expressing stages of discomfort due to cold, for it is the presence or absence of wind which really affects the human body. It is possible and, indeed, common to be bathed in perspiration when sledging at minus 50° Fahrenheit in a calm, and even more common to acquire serious frostbites at a temperature 70 degrees higher but with a strong wind. A still stranger paradox occurs when sledging in summer, in the Antarctic in particular, when, under the conditions of a sunny day but a fresh wind, a man may have the windward side of his face going white with frostbite, and the leeward, sunward side of his face going dark with sunburn. The real enemy of the traveller is, in fact, the wind and not the cold by itself.

There are certain attendant inconveniences of great cold which need to be experienced to be appreciated. Thus the condensation of all the breath on one's face and headgear becomes quite a nuisance. To step out of a hut or warm tent with damp clothes on and feel them quickly become stiff like armour is also unpleasant, and may even lead to curious consequences, for men have allowed this to happen while their head or limbs were set in an unusual position and have had to stay in that position until the next chance of thawing released them. Less irksome, but also inconvenient, is the fact that a man cannot smoke a pipe in great cold, for his breath congeals in the stem and blocks it up. Yet, as a whole, cold in itself is less to be feared than wind, and, provided there is food and dry clothing, a party can weather almost any degree of cold. Possibly the most uncomfortable journey ever made in extreme cold was that made by three men of Captain Scott's expedition in midwinter. Reading the account of that journey, described graphically by Cherry-Garrard, one realizes that, if conditions had allowed for dry clothing and dry sleeping-bags, more than half of the danger and discomfort of that journey would have disappeared.

Such, then, are some of the general attributes of the polar regions which exist in greater or less degree according to the part visited, and which have to be imagined as a constant background to life and travel there.

CHAPTER II

THE SCENERY OF THE POLAR REGIONS

> Breasting the slow-heaving, limitless swell,
> Child of the snow and the far-reaching tides,
> Proudly I swing, sheer-riven, clean-cornered,
> Dipping awash my immaculate sides.
>
> "The Barrier Berg": *South Polar Times.*

In this chapter we will attempt to capture something of whatever appeal there may be in polar scenery, whether of the beautiful or of the awful or of the merely monotonous.

Let us imagine ourselves on board of a polar ship, and for our purposes it hardly matters whether it is bound to the North or to the South. The ship will be a wooden one, but in other respects it will look rather like an old-time barque which has been equipped with an engine and at least looks seaworthy, if not exactly graceful. It will be marked out from other ships, however, by having a barrel, or crow's nest, affixed to its main mast. As the polar regions are approached there will, sooner or later, be a distinct whitening of the sky towards the horizon ahead—the reflection from floating ice, which is called "ice-blink"—and before long little dots of shining white will be seen on the dark sea. The first exclamation of the newcomer will certainly be: "But how exactly what I expected!" In other words, the fringe of the pack ice, composed of fragments of very white ice, can be quite easily imagined. The ship master pays little attention to such "brash ice," as he calls it, which does nothing to impede his ship; but the size and number of pieces rapidly increase until the ship is forced to edge between the larger blocks or even ram them so as to cause a crack to rip across the white surface in a zigzag and allow the ship to forge slowly through. Once well within the pack ice, however, the traveller, whether new or old, will fall a victim to the charm of its infinite variety in form and colour.

The main difference between North and South would be that in the Arctic the ice will soon be much more formidable and closely packed, and it is always much more irregular. Perhaps the most unlooked-for feature in pack ice is that it is the exception and not the rule to find large, smooth floes such as one would expect. Such smooth icefloes form, of course, at every onset of winter, but the ceaseless drift breaks them up, piles their edges together, and ultimately gives rise to what used to be picturesquely described as "the hedgerows of the Arctic." Indeed, it is not an inapt analogy to compare the Arctic pack ice to a series of irregular fields where snow takes the place of grass and irregular lines of piled-up blocks of ice represent the hedges. Should it be near the end of summer and the nights be cold, one is soon presented with the whole process of the formation of sea ice. At first the surface of the sea, which must be calm, appears to be covered with a sort of film, which ultimately makes it look a little milky; the film consists of a mesh of ice crystals interlocking. The small wavelets, however, will not at first allow these to form into a continuous sheet, so that, after an hour or so, one has the mottled effect of a vast number of tiny little ice tartlets with upraised edges, caused by the jostling of their neighbours, each growing thicker almost as one watches them, and every now and then freezing to each other. Finally, the damping effect of these innumerable discs of thin ice on the waves will allow something approaching a large sheet of ice to form. It will be dark in appearance, and is actually known as "black ice"; it will be so flexible that no one should venture to walk on it until it is at least five or six inches thick, and even then it visibly gives under a man's weight.

Should the temperature fall really low, there will be a display of "ice flowers," a series of thin spicules of ice striking up into the air from a nucleus of briny solution. These ice flowers are very short-lived, but very beautiful while they last. They cover the ice with irregular patches, but tend to run in lines along minor fractures.

If the ship is able to proceed well into the Arctic pack, it will meet with really old and stubborn floes.

Ice which has seen several winters, has been subjected to the throes of pressure and to the dissolving of summer rains, and has survived as dense, hard, and almost fresh ice, so uneven as to the surface that it may be a complete barrier to sledge travel. These very old floes, which have been given the picturesque, if somewhat misleading, name of "Palæocrystic ice," are the last to disappear when, in due course, the pack ice, taken by the southward currents, finally reaches latitudes where it is gradually melted away. A walk across such pack ice is not the simple matter that it might appear. It is usually covered with a certain amount of snow, except at midsummer, when pools of fresh water take its place. The walk, however full of interest, is one to be careful about, for there are many pitfalls and barriers, either of thin ice which will let one through, or even of insurmountable pressure ridges. But it is this very changeableness of surface and contour which makes the pack ice so full of interest, always provided that the sun is shining and that the weather is calm. On grey days or with strong winds, on the other hand, the pack can be a very miserable place.

The many forms into which the irregularities of the pressure ridges are carved by the action of wind or smoothed off by snowfall are themselves of interest, but when, as in bright sunshine, they are full of delicate colour, ranging from delicate lavenders to the most electric of blues, the scenery in miniature can be appreciated even by those with the dullest eyes, and monotony in the ordinary sense is rarely a feature of the landscape.

The practised eye will soon be able to discern by form or texture the age of any ice block, its degree of firmness, whether it will give fresh or brackish water;

in a word, its suitability or otherwise for the purpose in hand.

From the large old floes to the smaller icebergs of the North is but a step in size, though the origin is quite different, the icebergs being always derived from land ice. In picture and in story we are most familiar with icebergs far away from pack ice, and perhaps their beauty is enhanced by the contrast with the dark water and the waves dashing against them. Their true home, however, is in the polar regions proper, and the first part of their career is normally passed surrounded by sea ice, which to some extent protects the iceberg from the action of waves and certainly provides a striking contrast as to size. Here we must distinguish carefully between the icebergs of the Arctic and those of the southern regions, for there are many differences. In the North icebergs are comparatively rare, and, coming as they do from the ice of glaciers pouring off the giant ice cap of Greenland, already much crevassed before they reach the sea, they are normally of very hard, dense ice and of irregular and even pinnacled form. It is true that there are small, flat icebergs from Franz Josef Land and North-East Spitsbergen, but these are insignificant in size compared to the tall Greenlanders. The latter tend to drift down the coast of Labrador and form, as we know, a menace to navigation off the coasts of Newfoundland and off the Grand Bank, where the International Iceberg Patrol is now established to report the presence of bergs and attempt to destroy them.

In the Antarctic, however, the normal source of icebergs is from the flat "barriers" so typical of that region. These barriers are immense fields of floating ice, formed, not from sea, but from snowfall accumulating year after year, and they range in size from that of the Isle of Man to that of all France. The icebergs are, therefore, almost always tabular in shape with a stratification, and in the upper layers, at all events, are composed of compressed snow rather than of hard ice. They are also far more numerous and far larger than the northern ones, though they are rarely more than 200 feet in height above the water surface.

Naturally, icebergs, being much larger and more resistant to the erosion of the waves and the lapping of warmer waters, will generally be met farther from the polar regions than sea ice. In appearance they are very awe-inspiring, whether they are seen on a clear, sunny day or through the loom of fog, and it is, of course, impossible to separate from our minds the thought of what a menace these floating islands of ice must be to the shipmasters. When met far from its attendant pack ice, an iceberg will be undercut and encaved by the waves, and often its equilibrium will be sufficiently uncertain to cause it to have a very slow, careening motion, which, if the berg is a large one, will have such a long period that it is quite difficult to detect the slow tilting. Only to a few lucky travellers has the sight of an actual capsize been vouchsafed.

The play of the sunshine on its glistening walls, the blues and emeralds of its cracks and crevasses, the icicled appearance of its overhanging cliffs—in a word, its majesty of form and colour—are almost impossible to do justice to in verbal description. Seen in the pack ice, it towers above the flat floes and provides a more than pleasing break to an otherwise flat horizon. Sea ice itself is moved more by wind than by water current, but an iceberg with at least five-sixths of its bulk under water pays little attention to the direction of the wind.

It therefore moves through the surrounding pack ice, brushing it aside or pressing it up like so much paper. This stealthy movement of an iceberg may be an awkward matter for a ship held up by sea ice too thick to pass through, for, if she has banked fires and there is no wind, there is nothing to move the ship out of the path of the iceberg. It has even been necessary on occasion for a whole ship's company to tail on to hawsers from the bows of the ship and walk her along with painful slowness.

Adventures with icebergs are a common experience with most polar explorers, and one of the most thrilling is that of the *Erebus* and the *Terror*, under Sir James Clark Ross in 1842, which during a gale had to find a way between two of the giant Antarctic bergs to reach safety, not without battered yard-arms and broken bowsprit. The normal life of a large iceberg depends, of course, upon how soon it reaches warmer waters, but in the North it may be as long as five years, and in the South perhaps ten. In every case its final dissolution is into fragments known to the whalers as "growlers." These are comparatively small masses of ice hardly showing above the water, but the size of a house under water, and are therefore an even greater danger to a ship than their more visible parent.

The Greenland berg, with its towering pinnacles, is more beautiful than the squat southerner, but the latter is, perhaps, more impressive from its greater size, its clean-cut sides, and its regular shape. In the southern seas bergs up to thirty miles in length have been seen, and, indeed, they have often been mistaken for land ice or even snow-covered islands. Occasionally a southern berg is dome-shaped, and then its resemblance to the low hills of an island is extraordinarily close, but truly ice-covered land is usually easily recognized when met with.

The popular conception of polar lands is, no doubt, that they are perennially covered with snow and ice, but, though this is an apt description of the Antarctic continent, it will not do for the Arctic regions. Greenland, indeed, is almost entirely covered with an ice cap, but many of the other large islands within the Circle, especially those to the north of Canada, have no permanent covering, and for many months in the year are quite bare. One has only to read the accounts of such explorations as those of Parry early in the last century, or of Stefansson in the early part of this century, to obtain a clear idea of how peculiarly " un-Arctic " some of those bare lands can be. Valleys which become meadows of wonderful Arctic flowers, grazed over by caribou and musk-ox and fertilized by myriads of insects, are not what one would expect of lands beyond the polar circles, and do indeed lend colour to the picturesque term of that great explorer who named it the " friendly Arctic." Nevertheless, it will not do to consider the polar regions too friendly, for even in the Arctic, and less still in the Antarctic, the polar lands do not always support life which can be of use and sustenance to mankind.

The lands themselves will depend for their appearance chiefly upon the structure of the rocks of which they are formed. Consequently, we find that the Franz Josef Archipelago is composed of flat-topped islands of nearly horizontal strata, each a small plateau in itself and often covered with a miniature ice cap. This is dull scenery, for the most part, since, in spite of the contrasts in colour between the different beds of rock and the ice cap itself, there is insufficient interruption in the skyline to provide real mountain scenery. In Spitsbergen, on the other hand, as its name implies, the rocks on the west, at all events, are much folded and tilted, giving rise to serried peaks and deep valleys instead of a continuous plateau and ice cap. Therefore one sees bare, steep hillsides enclosing dark valleys, occupied usually by snow-white glaciers, but occasionally by mud flats, which are only beautiful during the short flowering season of the plants. In Greenland there is somewhat similar scenery, and in the two large fiords on the east coast the great elevations of the mountains, together with the really extraordinary contrasts of colour in the rocks themselves, makes the scenery beggar description. In the Canadian Archipelago the elevations are much slighter, and the landscapes are, by contrast with Greenland, somewhat monotonous and unattractive.

On the Antarctic continent we have to remember that only a very small fraction—probably less than one part in 100,000—is ever bare rock, all the rest being covered by an ice cap which may be anything up to 2,000 feet in thickness. Again, the structure of the rocks governs the type of scenery, so that in Graham Land on the American side there are miniature Andes, while on the Ross Sea, or Australian side, the horizontal strata tend to give flat-topped mountains. Everywhere there is a far greater range in height than in the North, and the outpourings of ice from the cap are so great that normally glaciers do not remain enclosed in the valleys but push far out to sea as floating glacier tongues. Further, the lower annual temperature gives little chance for a universal thaw such as takes place in the Arctic, and consequently there is an absence of water action and glacial rivers. On the ice cap itself, where few parties have penetrated, there can be no scenery in the ordinary sense of the word, but it is not, as one might expect, a level plain of snow. It consists of vast rolling downs with shallow valleys between them which, in the strong light of the polar summer, show up by the incidence of the shadows. But these valleys are different from those we know, in that they have no regular trend and may even be basins. A basin or depression whence water cannot escape is one of the rarest types of land form, and, when met with on a snowfield, it strikes one as extraordinary and puzzling. Thus a party of scientists, on coming to such a basin about half a mile across and perhaps 120 feet deep, was immensely amused to find their sturdy but somewhat unintelligent seaman companion scratching his head hard and muttering: "Well, I'm blamed if I ever thought I'd see a soup plate made out of snow!" Lastly, one may mention that at either pole there is a certain amount of volcanic activity, best instanced in the North in Iceland and in the South in the Ross Archipelago, which has the active volcano Erebus as its most recent phase of activity. But there are many volcanoes in the world which are above the snowline, so that there is nothing peculiarly polar in the scenery produced.

Summing up the general effect of polar scenery, one may say that as a rule it is the vast distances and the lack of living objects which form its chief characteristic. Further, it must be remembered that ice may take so many forms, sometimes beautiful, sometimes grotesque, that there is always something new to enjoy in every polar scene. The lack of trees in particular makes the polar landscape comparatively uninteresting, and an unbiassed observer would probably say that, except for the magnificence of its scale, polar scenery was far less enchanting than that of the Alps or any other really mountainous and snow-covered region.

CHAPTER III

POLAR TRAVEL

If you turn the furside outside, as you say it grows on that side,
Then the hard side's next your own side, which for comfort's not the right side,
As the hard side is the cold side, and your skinside's not your warm side.
"The Sleeping Bag": *South Polar Times.*

It is not proposed in this chapter to sketch the history of polar exploration, for there are whole libraries as well as single books dealing quite adequately with that subject. Yet with all this literature available it does seem that the popular idea of the difficulties and of the incidents of polar travel is somewhat unreal. On the one hand, there is the armchair student who magnifies the hardships and the terrors principally because polar narratives have tended to emphasize the accidents and unpleasantnesses. On the other hand, there is the man who has no sympathy with exploration because, as a whole, it produces no economic benefits, and who is apt to assume that explorers go to these regions to have a good time. That this is not an exaggerated case is shown by the fact that a prominent politician in one of the Dominions published such an opinion just before the departure of a large expedition. Thereupon the leader of the expedition promptly invited him to join it so that he could share the luxury and ease he predicted, but no more was heard of him. Only the briefest summary of the history follows, therefore, and then an attempt is made to give a picture of modern polar work.

The history of polar exploration can be divided into three fairly definite phases, each with its own methods and aims. There was first a phase when to travel to the North was a project almost too fearful to contemplate owing to the dread both of the perils of ice and of the darkness of winter, and when nothing but the strongest motives were sufficient to lead people to undertake such a hazardous venture. The purpose at this time was to find an alternative route to the Spice Islands of the East, so we find companies of merchant adventurers fitting out expeditions to accomplish this journey.

It will be noted that the exploration of the polar regions was not an end in itself, and, indeed, that purpose did not present itself to mankind until several centuries later. Spurred on by these and other comparatively mercenary motives, we find expeditions by Frobisher, Hudson, Barents, and others which failed in their final purpose, but which, as a side issue, found a certain amount of profit in the regions and certainly brought the world a clearer knowledge of the conditions. The element of romance was at once strong in their narratives, and the world from the first became accustomed to expect strange tales from the Arctic. Frobisher's supposed discovery of gold, for instance; Henry Hudson's dreadful death with his small son by being marooned in the North; and Barents' first winter spent on Nova Zembla, are all stories which still can stir the reader. More thrilling still is the fact that more than two centuries after Barents and his company had

had to spend their miserable winter in the North, their house was discovered by a Norwegian captain intact and with all the domestic articles exactly as the Dutchmen had left them when they took to their boats and sailed homewards.

This earliest phase gradually changed into a more rational one, in which the purpose was again purely economic—the exploitation of whaling and sealing—when the age of pure dread had passed and ships' companies became accustomed to the ordinary summer conditions of the polar seas. It is extraordinary to read that at one period there was an annual summer population in Spitsbergen of many thousands of men, chiefly Dutch, who occupied for a few months a small township on the west coast for the blubber industry, which was appropriately known as Smeerenburg, or " the greasy city." There were as many as two hundred whaling ships working in these northern latitudes in a single summer. Even at that time, however, there was so great a fear of the months of winter darkness that it was impossible to get men to remain there for a winter. It was proposed by the English to grant freedom for a party of men condemned to execution if they would spend a winter, but the men refused, preferring the swift axe to a slow death by cold or whatever it was they feared. Four Russian trappers, however, spent six years deserted by their ship in East Spitsbergen, and the three survivors, though they told a tale as thrilling as any of Daniel Defoe's, were a living proof that the terrors of the winter were not too great for human life to bear.

The last phase began before the whaling had finished in the exploration of the unknown parts of the polar regions for exploration's sake. It is true that the

North-West and North-East Passages were still the advertised purpose of these expeditions, but the explorers and their supporters knew quite well that these passages, if ever made, were not likely to be of commercial value. In fact, the search for these passages, like the later attainment of the poles, became a useful peg upon which to hang other and more definite aims in exploration. As time went on this exploration became more and more scientific and pure in its motives, and, although the methods are now somewhat different, the phase has not really changed.

It is true that the political significance of exploration has of late years become of great importance, but most of the expeditions north and south in the last fifty years have had as their main motive either the accomplishment of a feat such as reaching the pole or a genuine plan for exploring the unknown. This phase produced what may be called, for want of a better term, the professional explorer—that is to say, a man who, by reason of his success or his persistence, went time after time to the polar regions and became an authority and an example. For the first time in history, in fact, one began to hear the phrase " the lure of the Arctic," and, since these explorers were generally of a type competent to describe their experiences, the literature of the polar regions soon became extensive.

The immediate spur to exploration was, however, not always of this character; in fact, the greatest onslaught upon the unknown parts of the Arctic was occasioned by a disaster of a particularly overwhelming kind. The last expedition of Sir John Franklin, with a large party in two well-found ships seeking the North-West Passage, simply vanished into the unknown and gave rise to a number of search expeditions, which for many years attempted to add to the meagre story of what had happened to the fated ships. The success in their main purpose was but small, but in the process they not only discovered much territory, but they learned new methods of work and trained a generation of sledgers such as has never been equalled since. As in all other types of discovery, the history of polar exploration is built round the names of famous men, and the long roll of honour of the Arctic is itself a witness to the qualities demanded for successful endeavour in such a service. As examples in later times we may mention Parry, McClintock, Kane, Greely, Nansen, Peary, and Koch, while the Antarctic has its own list including the names of Ross, Scott, Shackleton, Amundsen, Mawson, and Nordenskiold.

That the North should be well known long before the South was but natural in view of the difficult approach to the latter; yet, once serious expeditions began in the Antarctic, rapid progress was made in certain sectors, and the two poles were finally reached by man within three years of one another. There is still a great difference in our knowledge of the two ends of the earth, however, for, while in the Arctic there is now hardly room for the existence of any great feature yet undiscovered, in the Antarctic there are still thousands of miles of coastline to be followed and space to contain great mountains or vast gulfs yet unsuspected.

Possibly one reason for the general interest in polar work is that even to-day there is a hint of the mediæval in the setting out of a ship with its company, which in a few weeks will be completely cut off from any approach to civilization and which may bring back news which in a small way will be as strange as that of the sailors of the Tudor age when they returned from voyages Westward-ho. This quality has been disturbed somewhat by the advances of wireless and of air navigation, but, even so, it is likely that polar travel will continue to attract those men who possess something of the Elizabethan spirit. Robinson Crusoe, it will be remembered, did on some rare occasions sit down and take stock of his situation and give thanks for his independence of the rest of the world and his ability to suffice unto himself. The polar explorer, too, takes some pleasure in the fact that he is cut off from the world and yet can make shift to do without it in an existence which is simplicity itself, where taking thought for to-morrow consists only in foreseeing provision of food and shelter and is free from the complications of letters, newspapers, telephones, and social or business engagements.

Perhaps the most interesting study in the history of polar exploration is the evolution of methods of travel. As we have seen, the two first phases of polar exploration—that is the search for the passages and the era of whaling—were not concerned particularly with travel other than by ship, but in the beginning of the nineteenth century, when discovery for its own sake was becoming fashionable, it was realized that the ship must become, in a sense, a headquarters from which land or ice journeys must be made by other means.

It is extraordinary how slowly civilization, as represented by these early explorers, realized that the Eskimo had evolved throughout long centuries the most reasonable and apt methods of making journeys. Certainly the idea of a sledge to slide over the snow was soon appropriated; in fact, it was quite a common mode of transport even in England for snowy weather and steep slopes. But the idea of using dogs to pull the sledges took a long time to appeal to these early adventurers. So we find that Parry, in his first venture to reach the Pole by sledging over the Arctic pack north of Spitsbergen, was wrestling with entirely new problems. He wisely decided that he must take with him boats of some kind in case he reached open water or missed his ship on returning, but to take ordinary whale-boats and to construct massive sledges for them to be hauled by men with ropes over their shoulders showed an ignorance of the pack ice surface and the ability of men to wrestle with such loads which to our present knowledge seems almost foolhardy. But Parry was the first to correct his early mistakes, and, when on a later voyage he established a headquarters in the Canadian Arctic Archipelago, he laid the foundations of the sledging equipment which accomplished so much in the early half of that century by man-power alone. Even so, he was averse to giving up entirely the idea of wheel transport, and he took a sort of hand-cart, which was used on Melville Island.

To this day there are places in the Arctic where the absence of snow does make wheel transport a more efficient method than sledges, but these are few in number; the actual vehicle for carrying provisions was only a small section of the whole problem. The early sledgers had to devise without experience methods of hauling the sledges, methods of cooking, rations, sledge harness, tents, and a number of other details of travel which now are all stereotyped. In the matter of food alone their difficulties were enormous and their ignorance vast; at that time scurvy had not been conquered, but was kept in abeyance in ships' companies by the use of lime-juice and other deterrents, few of which were applicable to the conditions of sledging. Indeed, next to choice of transport, the greatest problem before a leader was how to conserve the health of his men, and much of the melancholy in the narratives of last century was due to the ever-present fear or actual occurrence of scurvy in an expedition. Perhaps the greatest sledger of that period was Leopold McClintock, and reference to his narratives will show the kind of difficulties and the ceaseless experimenting by which alone he was able to accomplish the extraordinary journeys which he made.

Later in the century, explorers, especially Americans, began to use the Eskimo as helpers in travel and to adopt their method of transport with dogs; and, although there were relapses from this advance, such as when the British expedition of 1875 did all their work by man-hauling, it became more and more established that the most economical way of covering great distances was by the use of dogs. This method was perfected by Admiral Peary in his many journeys in the North, though it must be remembered that he still trusted largely to the Eskimo themselves as dog-drivers. Meanwhile the general advance of civilization had automatically solved a number of the minor problems. Expeditions were able to buy provisions in a wholesome yet concentrated form, clothing was more readily adapted to the climate, and cooking methods were improved. The greatest advance in methods of sledging was due most certainly to Dr. Nansen, who, with a vast experience and an inventive mind, devised sledges, cookers, and tents on which all later gear has been patterned.

Another factor in the evolution of sledging was also rather slow in coming into fashion, and that is dependence, to a greater or less extent, on the game which in the Arctic is nearly always to be met with at certain seasons of the year. The great exponent of this method of "living on the land" is Mr. Viljhalmur Stefansson, who has made extraordinary journeys himself with little other provision than that which he shot by the way. Nevertheless, a perusal of his own narratives will show that it is not given to every man to be as keen a hunter as he is himself, and that nothing less than some years of training in the North will make the ordinary man capable of hunting the wary seal or building the snow igloo or even of living upon meat alone with the ease and efficiency of the Eskimo. Perhaps a better instance of "living on the land" than any other was the journey of Nansen and Johannsen for fifteen months over the polar pack ice when, after a few weeks, their food was almost entirely derived from the seals, bears, and walrus which they were able to shoot. Their adoption of the kayak, or light Eskimo boat, was another instance of how perfectly the white man had adapted himself to the century-old methods of the natives of Greenland.

Neglecting for the moment the use of the air for polar exploration, we may say now that modern Arctic exploration depends for its efficiency upon the use of dogs and other Eskimo methods. In the Antarctic a somewhat similar evolution is to be recorded, but, since there was no land exploration in that region until this century, their methods were fairly cut and dried from the beginning. In this case personal preferences ruled in a curious way, so that man-hauled sledges became, in a sense, the fashion in the South long after they had been almost entirely superseded in the North. Captain Scott, who was the pioneer of sledging in the Antarctic, tried dogs, but his experience was an unhappy one; his dogs were not good, their food was tainted or of the wrong kind, and he and his drivers were inexperienced. The result of this first attempt was to set him against dog transport, both for reasons of sentiment and efficiency. His main journeys, therefore, were made by man-hauling, in a great part.

Sir Ernest Shackleton tried pony transport, and on the peculiar conditions of his journey they proved a partial success, so that they were again used by Captain Scott in his last journey. They cannot, however, be regarded as a real success, and the contemporaneous journey of Amundsen to the South Pole with dogs was a crushing rebuff to every other form of transport. It must be remembered that Amundsen's success was due largely to the character of his dogs and to the experience of his drivers; for other leaders, such as Nordenskiold and Mawson had tried them in the South without any very marked success. Since the Great War all other methods of travel have been temporarily eclipsed by the use of the aeroplane or airship, which have already proved their capacity for transport in the polar regions. The air has even been acclaimed as the future route for all polar exploration, but this is not so. For rapid reconnaissance the aeroplane has, of course, no rival, but for exploration in the full sense of the word the dog sledge and the man-hauling party will still be called upon, as in the past.

The ideal methods of the future will be a combination of aeroplane and dog sledges, and this combination is already being experimented upon with partial success by the American expedition under Richard E. Byrd in the Antarctic.

This brief review of the evolution of methods of travel has not introduced us, however, to the realities of journeys in the polar regions, nor, indeed, do the narratives of such journeys always give a clear picture of the minor incidents of such travel. We shall now attempt to give such a picture by recording a small journey by sledge; it shall be a man-hauled party, for that gives the fullest experience, but the necessary alterations for a dog party are not hard to imagine. To begin with, the equipment, being of a highly specialised type, must be briefly described. The sledge, for instance, will probably be made of ash with hickory runners, and is so put together with lashings that it is completely flexible, and when fully loaded will accomodate itself to an uneven route, so that it looks for all the world like a giant, fat lizard sliding over the surface. The packing of the sledge will be attended to by the most experienced member of the party, since any losses from the sledges *en route* may be serious and the liability to capsize must be reduced to the minimum. The food, in strong canvas bags or even in low, thin boxes, therefore, will form the substratum in the centre of the sledge. At the after end, where least damage is likely to take place, the instrument box will include the all-important Primus stove, together with the theodolite, thermometers, and such other scientific instruments as are required. Usually the rather large "Nansen" cooker, made of aluminium, will be strapped to this box; in the fore part of the sledge there will be the tins of paraffin for the Primus. The sledge will have a curved front made of strips of cane which will yield to a small extent if it rams a hummock, and under it, fastened to the forward uprights, is the large rope by which the whole concern is pulled. This is fastened to the bow of the sledge by a thin lanyard strong enough to keep the rope off the ground, yet weak enough to give way if the men fall into a crevasse; when it breaks, the men, if lucky, will be supported by the main structure of the sledge instead of tilting it on end to dive down the crevasse after them.

The man harness will consist of a broad band of canvas fitting loosely round the waist and held to the shoulders by braces made of broad lamp-wick; to eyelets in the back of this harness a permanent "tail" of Alpine rope is attached, and this can be rapidly fastened to the main toggle of the sledge. If it were a dog sledge there would be a long trace stretching forward from the bow, preferably with a wire centre and a number of toggles or loops along its length, to each of which a pair of dogs would be attached by harness varying very much in design, but arranged so that the pull came upon the shoulders of the dog. The men's dress is, perhaps, the most surprising item, for, contrary to popular fancy, it will not consist of furs. Fur clothing is far too warm for really heavy work, and, though it can be used in dog-driving, it must even then be made on the Eskimo pattern so that there is free exit for perspiration, and there must be facilities for periodically drying the sodden mass which it rapidly becomes. The man-hauling party will have ordinary woollen underclothing of a slightly thicker pattern than for winter life in England, and this will be covered by windproof material of closely woven texture which is loose and can be put on or taken off at a moment's notice. The weight of clothing worn is not more than that usual for winter wear in temperate climates. On the feet there will be finneskoe, or loose boots, of reindeer-skin, and on the hands there will be loose wolfskin mits, hung by a lanyard to the neck so that they cannot be mislaid when the hands are taken out of them to do some small fastening or other finger work.

Napoleon is credited with saying that an army marches upon its belly, and so does a sledge party; but it more emphatically marches upon its feet, in the sense that the care of the feet and footgear is of the very first importance. However useful our feet may be in a general way as a support, they are nothing less than a nuisance in the polar regions, for two reasons. First, they are so far from the heart that the circulation is liable to fail there earlier than elsewhere, with the consequent annoyance of frostbite. Secondly, the feet in most men produce an astonishing amount of perspiration. Consequently, the feet must be kept warm and as dry as Nature will permit; after even a short march the socks will be thoroughly wet with perspiration and will freeze into a solid mass when taken off. Yet they must be taken off, otherwise their rapid conduction of heat will allow the feet to get cold. On a really cold journey, therefore, there is always the unpleasant business of sock drying, either by hanging them in the peak of the tent, which is not very effective, or by placing them next to the skin for the night. In either case the owner is lucky if he has not to wrestle in the morning with a sock which is more like a boot for stiffness.

The best way to keep the feet warm is to allow them to move perfectly freely when walking; an ordinary boot will not permit this, and even a loose ski-boot will soon bring on a frostbite in cold weather. In the thin finneskoe the sole of the foot moulds itself to the unevenness of the ground and has perfect flexibility, and the Indian moccasin is somewhat similar in its effect, but is usually worn rather too tight. The fur boot is fastened to the ankles by strips of lamp-wick, this material being the most handy for fastening with numbed fingers. Attached to the blouse of windproof material there should be a windproof helmet which may be slipped over as need arises, but the really tender parts of the face—that is, the nose and the cheekbones—cannot be adequately protected by the helmet. Almost every expedition in history has wrestled with this problem of protecting the nose and cheeks, and each one has devised some patent or other in the form of a "nose nip" made of fur or material to fasten across the face in a bad wind, but none of them are of permanent value, for the breath condenses on them and the face soon becomes coated with a mask of ice, which is even more uncomfortable than bare cheeks. A frostbite is, of course, nothing more nor less than the freezing of the surface of some part of the body, and superficial frostbites are an everyday experience. If they are attended to at once, by warming slightly with the hand or by other means, they will "come round," accompanied by very unpleasant feelings somewhat like toothache, and the final result will possibly be no worse than a blister from which the skin gradually breaks off. But should the freezing be allowed to get far beyond the surface it is a much more serious matter, for as soon as the frozen capillaries thaw they will burst and a kind of blood-poisoning results.

With sledge loaded and the men properly clothed, the start is now made. It soon becomes apparent that hauling a sledge requires concerted action and almost as much teamwork as rowing a boat; the team must keep in step, and the long-legged man must not take too great a stride, nor must the short-legged man be allowed to trot. Any unevenness in the pull will cause a jerking effect, which soon tires a man. In a word, the men must set themselves to learn the simple principles which every team of horses has to acquire. It follows, again, that the best team will be fairly uniform in size and strength, so that no one has to take an unnatural step. On a smooth surface such steady sledge-hauling may be just as great a delight as pulling a boat over calm water, but, of course, such conditions are the exception, and the sledge is constantly either held up or running free, so that the tension on the trace is never the same for very long. In fact, almost the first day the team will begin to appreciate the importance of the snow "surface," this being the most convenient term to describe in one word the sliding effect of the snow on the sledge, and for the rest of their sledging lives the team will think of little else when at work.

The actual mechanics of the sliding action of a sledge over snow is still not very well understood, but every sledging party knows that all sorts of comparatively minor factors affect it, of which temperature is, perhaps, the most important. At minus 30° Fahrenheit the sledge may be running quite nicely, but at minus 45° on the same surface it will be like dragging wood over sand; again, near the freezing-point there will be critical points when the sledge runners gather snow and lose all capacity for sliding. On sea ice a small amount of salt on the surface may pull up the sledge and so destroy the sliding effect that there is nothing for it but to "pully haul"—that is, to face the sledge and jerk it along by hauling on the traces as one would upon a halliard. Naturally, every leader will have his own routine when on the march, but a general average would probably be that of a halt for three to five minutes every hour, possibly for nothing more than to adjust traces and ease the limbs, possibly actually to rest if the pulling is severe. Here we touch upon the most important subject of sledging psychology.

It can be readily understood that such heavy and monotonous work as pulling a sledge over endless plains of snow will have curious effects upon the minds of different individuals, but a few of these effects are common to all, and the wise leader of a party will not fail to pay some attention to what is going on in the minds of his companions. The work is always too hard for conversation, but, except when there are many pitfalls or irregularities, the mind is free enough from the incidents of the trail to do a certain amount of rather dull thinking. The thoughts of a man while doing such work are not keen enough to be classified as constructive, and the result is that sledgers think rather for the sake of keeping their minds occupied than with any set purpose before them. In other words, if they did not think, but merely allowed their minds to receive impressions from the ceaseless plodding of their companions or the details of the snow at their feet, they would probably begin to fail mentally rather soon. Their thoughts naturally run rather to the affairs of the day and of the business in hand and, naturally, the break for meals, or even the hourly halt become milestones in this process of thought. Thus, should the leader not call a halt until long after the established mealtime, he may set his companions' thoughts "fussing" until they build up a minor grievance. The leader himself is very much better off, for he knows exactly what he proposes to do, he has the choice of the route to occupy his mind, and altogether he is much more mentally free and alert than his companions.

Take such a small matter, for example, as a chafe on the heel. If it happens to the leader, he will either be too busy with picking his route or thinking of what they will do next to worry about the minor pain, or else he will call a halt and adjust his footgear. The follower, on the other hand, has ample time in which to worry about that small ache, yet, unless it is really troublesome, he will not think of asking the leader to stop to set it right. Presumably the same thing happens to dogs and horses when they are doing similar work, and nothing enables a man to understand the mentality of animals more clearly than a long spell of pulling a sledge. Naturally, incidents by the way are the saving of a team from complete mental stagnation. In this respect the wide plains of the Antarctic, sometimes far out of sight of land, are far more monotonous than the Arctic pack ice with its ceaseless interruptions to smooth travel, or than a journey over glaciers or amongst mountains. The ponies used by Shackleton and Scott on the Barrier seemed to droop almost from the first day, and a kind of harmless insanity seemed to overcome some of them. The dogs, too, became quite listless and lost condition on these journeys when landmarks were out of sight. Their interest would awaken for a moment or two if they saw some dark shadow ahead or anything which had the remotest semblance of being alive, but on the whole the deadly monotony of their route seemed to produce more fatigue in them than the work itself.

From this long digression we must get back to our sledge party, now ending its first morning's pull and getting ready for the midday halt. Unless it is absolutely calm, which will rarely happen, it is far more comfortable and nearly as quick to have the midday meal under a tent instead of in the lee of the sledges. Different leaders have held very different opinions about the propriety of a temporary camp for the midday meal, but, except in summer weather or under very calm conditions, it is always wisest to set up the tent and to have a warm drink as well as the rest. Therefore, as soon as a good patch of suitable snow is sighted the word is given for the midday halt. One man seizes the tent poles, which are five or six poles held together by a leather cap at one end; he erects this structure in the form of a cone while two other men hold the skirting of the conical tent down wind from the tent poles and, as it bellies out with the wind, haul it over the poles. The fourth man has the snow shovel and has ready a few blocks of snow to put on to the skirting of the tent as soon as it is stretched over the poles. In reasonable weather this is the work of but two or three minutes, but with a strong wind and low temperature it may take ten minutes or even longer.

As soon as it is temporarily anchored the men pass in the floor cloth of canvas and the sleeping-bags to serve as seats; the Primus is also passed in with the cooker, which the cook rapidly takes to pieces, passing out certain parts to be filled with snow or ice. At lunch-time there is no camp work to be done, so the idle members come into the tent while the cooking is being done. Normally it hardly deserves the name of cooking, as it will be but a brew of tea, and the food itself will, perhaps, consist only of one or two biscuits, possibly with butter or even raisins.

It is the experience of many men that the morning work is always more exhausting than that of the afternoon, and occasionally such men will feel completely exhausted by lunch-time, but the break and the food, and more especially the tea, seem to call up fresh reserves of strength, and the afternoon work is then a small matter in comparison. The halt for lunch may be very short or there may be observations of various kinds to be taken. On a journey where distance is the main object it will be very brief indeed, but even under such conditions the followers will earnestly hope that the leader forgets the lapse of time, for every minute of the halt is a real relaxation. It is not unknown, in fact, for the members of a party to become unusually interesting in their conversation and stories towards the end of the lunch halt, in the hope—not always in vain—that they will interest the leader enough to make him forget to look at his watch. The length of the afternoon march will, of course, depend upon circumstances, but usually a party will go on until it feels decidedly tired. The camping arrangements for the night are then more careful than for the lunch halt; more snow will be put on the skirting of the tent, the sledge will have to be made secure against the wind during the night, and things tidied up generally, so that by the time the three outside men get into the tent the cooking will be well under way.

The universal rule is that footgear must be changed before the feet get cold, and consequently each man, except the luckless cook, has changed his socks and is reasonably comfortable by the time the thick soup made of pemmican and known as "hoosh" is ready for them. There is very little art in sledge cookery, but it does demand neatness and quickness if the party is to get the best from its somewhat monotonous food. Once the Primus is alight and roaring, and the component parts of the aluminium cooker are carefully arranged over it, the cook has time to undo the food bags, generally arranged to last a week, and to gather round him the few ingredients he is to use. He is sole rationer for each meal, and nothing but experience will show him how generous he should be with the materials. Naturally, it is better for a cook to end the week with an extra fat meal than a very tenuous one, but cooks have been known to overdo this to such an extent that they kept their party hungry for a week and gave them dyspepsia the last day. It is usual for each man of the party to take on the duty of cook for one week.

As soon as the ice is half melted in the inner pot of the cooker, the brown, greasy lumps of pemmican, composed of beef extract with a very large percentage of fat, are dropped into the cold water, and the cooker is closed up again so that only five per cent. of the total heat given by the Primus gets out into the tent. When the mass has come to the boil, the cook has to lower the flame of the Primus, rapidly deal out the pemmican into the aluminium mugs placed on the floor, take out the outer pot of the cooker, and pour the water into the inner pot to be brought to the boil for the tea or cocoa. This all sounds simple enough, but it must be remembered that there is not much room in a tent when the floor is uneven, when there are feet waving about with socks half on or off, and when, in the spring or autumn, the light is decidedly bad. Further, the cook's fingers, covered with old frostbites and quite insensitive to anything but great heat or great cold, are unable to grasp small, light things without risk of knocking them over. When these things are considered it will not be surprising that all too often a precious mug of pemmican is spilt on the floor, the Primus is allowed to go out, or perhaps even the whole meal is spilled by some clumsy movement. Still, even under such conditions the imaginative cook has a certain scope, and he will, if he is original, tickle the palate of his companions by various changes in the proportions of the ingredients: thus he may serve a thick hoosh either by using less water or adding biscuit fragments, or he may be generous or niggardly, as fancy serves, with such condiments as he has—pepper, salt, and possibly curry powder. If he is wise he will not attempt to experiment too far, for some people do not like sugar in their hoosh or curry powder in their cocoa. In a word, the evening meal is a real event, and it is up to the cook to make it interesting. The meal over, the cooker must be filled with ice for the morning, the tent door fastened securely, and the sleeping-bags spread out; the party then edges itself severally into them and settles down to a brief smoke or the writing of diaries before seeking sleep. On a cold journey the sleeping-bag is the one real friend to the sledging man, for only when comfortably in it has he some hope of getting really warm—at any rate, for the first few nights of the journey. It may be readily imagined that all the breath condenses in the bag itself and ultimately forms a layer of ice, which has to be thawed out before one can pretend to be at all warm.

The sleeping-bag is made with two flaps, which will fold over the long opening through which the sleeper inserts himself, and it can, therefore, be closed almost entirely, such air as there is coming only through the pores of the skins. For the first ten minutes in such a sealed bag a man has rather a desperate time of it, feeling more or less suffocated and wondering whether it is really safe, but after a little experience it is possible to get to sleep in such an atmosphere and to suffer no worse effects than a headache in the morning, which will pass off during breakfast, and even that is preferable to a sleepless night of shivering. The bag is made of reindeer-skin for really cold journeys, and the question soon arises as to whether it should be used with the fur inside or outside. There is considerable difference of opinion on this point. Many expeditions have preferred to use sleeping-bags made for two or three men, who in this way gain warmth from each other's proximity, but it is questionable whether the difficulty in getting to sleep thus wedged in the same bag with one's fellows is counterbalanced by the extra warmth. For very cold journeys, indeed, it is probably the better plan.

This is fine-weather sledging, and goes smoothly enough for experienced men, but for severe weather it may be imagined that many minor inconveniences combine to make the journey anything but comfortable, especially on a long journey. The snow that clings to the footgear and clothes, for instance, and is inevitably carried into the tent, must be scrupulously brushed off the floorcloth or the sleeping-bags, otherwise it will melt and coat the things with ice in time and make life a misery. The rime which gathers on the tent walls from the men's breath and from the steam of cooking must be kept down as far as possible, or else it, too, renders camping unpleasant. In a blizzard particularly does experience make all the difference between contentment and anxiety. If the tent is not secured by ample snow blocks, or if it is pitched in a bad spot, the party may spend anxious hours staving off disaster of one kind or another, whereas the experienced party may even welcome a short blizzard as a time of rest and are undisturbed by the whipping of the tent poles, the sharp cracks of the tent walls flapping violently, and the ceaseless swish of the drifting snow piling up outside. It is under such conditions that the tidy man becomes a treasure and the careless man may become a nuisance or even a danger. Sledging, in fact, calls for certain qualities, which do not necessarily show to great advantage in a normal life—good humour, unselfishness, tidiness, and foresight—and, indeed, many a "good, hearty fellow" of civilized life has become an extremely bad fellow as a sledging companion.

The conditions for the dog sledger are different to those explained, in that his own personal energy is not called upon to the same extent, and his attention must be constantly riveted upon his team. Having more occupation for his mind, and being less exhausted at night, he is naturally more contented with his work than the foot-slogger, who finishes each day just about tired out. On the other hand, the attention which a team demands, and the impossibility of leaving it for short side journeys on foot, do make dog sledging less efficient on the whole, except as regards distance covered. This is shown in part by the fact that Amundsen, on the journey to the Pole, recorded very few observations and never paused a day for scientific work, while Scott's and Shackleton's parties on a similar route brought back an immense amount of information in the way of specimens, maps, and meteorological observations. It is, perhaps, not unfair to draw the analogy of these sledging methods with touring by motor-car and by walking, for there is no question that the humble tramp sees far more of the country than the motorist.

Lastly, we have to add to these methods of transport the new wonders by air, but about them there is little to say, for as soon as the airship or aeroplane is in the air the problems cease to be polar in any way, and only become so again when it is necessary to find a landing-place. Experience is gradually devising means for landing an aeroplane upon snow surfaces, and the difficulty is not so much of devising skids and other suitable methods as to being able to tell from the air, on a dull day particularly, what sort of a snow surface is below the plane. Distance judging, which comes into every aeroplane landing, must be extremely difficult under such conditions; on the other hand, except on very broken pack ice, there is generally plenty of " run " for the plane after it has landed. The airship is a very doubtful quantity still in polar exploration. Amundsen in the *Norge* has proved what was foreseen—that the air itself in the polar regions is not much more difficult to navigate than elsewhere—but that the airship should ever become an important factor in exploration seems doubtful on two counts. First, the great expense of making and maintaining an airship is certainly prohibitive to individual explorers, and, secondly, its inability to land except at a proper landing station or under very rare conditions of weather makes it purely a bird of passage.

Polar travel, taken as a whole, has a delight and an exhilaration all its own, and it is the aspect of an expedition which remains most vividly in the minds of its members.

CHAPTER IV

PLANTS AND ANIMALS

Big floes have little floes all around about 'em,
And all the yellow diatoms couldn't do without 'em.
Forty million shrimplets feed upon the latter,
And they make the penguin and the seals and whales
Much fatter.

"The Protoplasmic Cycle": *South Polar Times*.

It is impossible to do justice in one short chapter to the peculiarities of the flora and fauna within the polar circles, but some popular misconceptions on the subject may, perhaps, be corrected. In the first place, there is a complete contrast between the Arctic and the Antarctic in this matter, for, while the former has what may be truly called a wealth of living things on land, the Antarctic has but a few mosses and no land animals whatever, unless we include two small insects associated with the mosses. The requirements of plant life are, in brief, some sort of soil, water in the soil at certain seasons, and a temperature above freezing-point for its growing season; and these are all to be had for a part of the year in the Arctic. Mere cold by itself will not kill plant life, as we are well aware when we read of the extraordinary low temperatures experienced in the Canadian and Siberian forests. Nor does a four months' darkness seriously affect plants when they have adapted themselves to such a long resting period; moreover, since plants grow by a process of photo-synthesis, it is clear that during the four months or so of continual light the plants will tend to make up for the length and intensity of their resting period.

So we find that in the Arctic, even to the north of Greenland, there is a flora which in number of individuals, though not in number of species, rivals that of sub-temperate lands; on any flat area which possesses enough loose material to hold water and form a foundation for roots there will be in the summer something approaching the meadows of the High Alps. Indeed, it is the lack of suitable soil rather than the other conditions which limits the amount of plant life in the Arctic. The species are similar to those of high Alpine regions, and their adaptability to environment is shown by the fact that it is possible to grow a large proportion of them on an English rock garden. It is true, for instance, that the brilliant purple saxifrage known as *Oppositifolia* is not exactly happy in this wet climate, and will blossom with reluctance, while in the Arctic it may cover whole areas with closely set blooms, but it does not die out. Various kinds of true grasses also grow, besides Arctic forms of some of our common flowers, such as buttercups, polemoniums, poppies, and campions. Of flowering plants alone there are over 120 species, and these will be found right up to permanent snow or ice almost anywhere in the Arctic where the other requirements are found. It is true, also, that Arctic plants must often have recourse to other methods of propagation than by ripening seed, but they have so adapted themselves to the curious conditions that vegetative reproduction is common to nearly all the species, which, therefore, tend to be perennials and to form spreading cushions. It is because of this abundant vegetation that there are plenty of animals to be found in the Arctic, but, apart from these grasses and other plants which form the food of the herbivorous animals, there are also many berries which are prized by the natives. There are, of course, no trees, and the low shrubs of birch, willow, and juniper are of creeping habit, though sometimes common enough to provide fuel. In the Antarctic, on the other hand, there are no flowering plants whatever within the Antarctic Circle, and the mosses are so few, either in species or individuals, as to cause surprise when found.

Outside the Circle in Graham Land or in the sub-Antarctic islands there is more vegetation. The explanation of this absence of vegetable life is to be found chiefly in the lower mean temperature of the summer season. Except in very favoured and sheltered spots, the air temperature of the Antarctic continent rarely rises above freezing-point, and, although each year there may be two or three days of strong thaw, it is far too short a period for the normal functions of vegetable life. There are also very few places on the continent where there is sufficient soil or loose material to form a suitable foundation for the growth of plants. This poverty of vegetable life is also the explanation for the complete lack of animal life. One of the two kinds of insects found on the continent has little enough to encourage it in its existence. When discovered, it consisted of eight or ten individuals floating about in a small pool of water on the top of a boulder. This pool existed as such for exactly two days that summer, and then the insects were frozen tight for yet another twelve months. The other insect is a small red mite with slightly greater freedom, since he was found running about on the broad leaves of the mosses, and not absolutely dependent on the existence of water.

Animal life in the North is well known, and, though the Eskimo have lived for centuries on what they could hune, there was no serious diminution until civilization came along with its firearms. Of the dry land animals, those of greatest importance from the point of view of food are the caribou of the Canadian Archipelago, a cousin of the reindeer of Europe, the musk-ox of the same area and of Greenland, and the polar bear. The musk-ox is a most exceptional animal in its ability to resist cold and to find sustenance during the period when all vegetable growth is at a standstill; yet it does so even on the bleaker parts of North-East Greenland, and, though it has died out in some places, it seems to have migrated with profit to others which, at first sight, appear even more inhospitable. It is practically proof against all predatory animals, for the bear will not follow it across rough ground, and the small animals are held at bay by the musk-ox habit of forming a circle when attacked. This habit, in fact, has become disastrous to it, because the modern hunter, once he has got the herd at bay and in a circle, simply picks off the animals one by one in comparative leisure. In appearance it reminds one of the North American bison, though in some other respects it is similar to a large sheep. The polar bear is not truly a land animal at all, and, in fact, prefers to spend most of its life on the pack ice. The Arctic foxes, very small and just as cunning and mischievous as the temperate product, also leave the land occasionally to keep company with the bears and derive their food from the leavings of the larger animals; but it is much more of a land animal, and, being of some value for its fur, it is, in Spitsbergen particularly, rapidly sharing the fate of the reindeer, which once populated the western side of that group. The tiny lemming, a small rodent of the Arctic regions, will, perhaps, profit by the reduction in the number of foxes, but it is not often seen and is of no great value. There is a certain number of true land birds in the Arctic, but very few of these winter in the North, and the birds, on the whole, may be classified together as more or less migratory.

Of marine life in both polar regions there is an extraordinary abundance; beginning with the smallest, we have in high latitudes the real home of the microscopic plant known as the diatom, which thrives here either because of the higher content of oxygen in the water or because of the long period of sunlight. The diatoms flourish to such an extent even amongst the pack ice that a tow-net hauled alongside the ship is soon so clogged with a slimy mass of diatoms that it ceases to function altogether. They not only colour the water a pale green, but the underside of icefloes in the summer and autumn become quite yellow with dead or dying diatoms. Upon these microscopic forms of vegetable life a host of small creatures thrive, and the whale food, or "kril," seems to consist of one or two varieties of crustaceans (amphipods and copepods), which live more or less directly on the diatoms. Fish are abundant in both polar seas, living, presumably, on the smaller forms just mentioned, and, in turn, providing food for the vertebrates, which, for the purpose of the moment, may be divided into birds and seals. In the North the seals of various species are abundant, some living entirely in the pack ice, some preferring the vicinity of land. Their enemies are many and include sharks and killer whales in the water and polar bears on the ice. They have still another danger, in that they must have holes in the ice through which to come up for breath, and if these are closed by pressure or watched by polar bears there would appear to be no alternative to the seal but to suffocate. All these seals are of the haired variety, and, though their pelts are useful to the Eskimo, they are killed by the thousand off the Labrador coast for their blubber and not for their skins primarily. The true fur seal does not belong to the Arctic.

The walrus of the North, with its mighty bulk and its curiously human expression, is in another category and appears to have no enemies on the ice, for polar bears will not attack it, and in the water it could fear only the killer whale. Its true enemy is the hunter with his rifle. In the South there are also several varieties of seal, all much larger than the northern types, and leading a somewhat different existence, for the simple reason that, once out of the water, they have no enemies at all, there being no polar bears in the South. They have coarse hair on the skin, and this is separated from the body by a layer of blubber up to two inches in thickness, and all live on fish and crustacea. One variety, however, known as the sea leopard, finds his best meal amongst the penguins, the swimming birds of the South. The absence of any enemies out of the water is proved by the fact that it is almost impossible to force them into the water by fright, and their hours of leisure are spent sleeping on the ice with never a thought of danger. The Arctic seal, on the other hand, has the habit of sleeping for only two minutes at a time and lifting his head to look for danger between each brief nap. The Antarctic seals, weighing from six to fifteen hundredweight, would be rather a proposition for the hunter without a rifle if it were not for this complete absence of fear on their part. As it is, the explorer or the ruthless sealer may walk right up to a seal, stun it by clubbing it, and then slaughter it in any way he likes.

Like all polar animals, they are very tenacious of life, and it is extremely hard to find a spot which is truly vital. Their enemy in the water is, again, the killer whale, and, although this animal is not polar in any sense, its habit of breaking up the thin floes so as to tip the seals into the water is certainly one which is learned in polar regions. There are even several cases of killer whales mistaking dogs and men for their legitimate prey, so far without mishap to the men. The killer whale is from fifteen to twenty feet in length, and, being armed with real teeth and being a fast swimmer, he must certainly be a terror to the seal family.

There is such a similarity between sea birds in temperate and in polar climates that we need not pause to describe the more typical Arctic species; but it must be remembered that the kittywakes, the puffins, and the glaucous gulls, besides other visitors to temperate seas, habitually seek the northernmost islands for their nesting season. Since the extinction of the great auk there are no longer any non-flying birds in the North, but in the South some eight or ten varieties of penguins still represent that curious type of life which possesses the form of a bird without powers of flight, and their characteristics are so unusual that they deserve some mention. Only two of these varieties are truly polar in that they spend the whole of their lives either on the pack ice or on the shores of the continent. Before an exploring ship has got far into the pack ice the ship's company will be vastly amused by seeing a flurry in the water close to a floe and one or more desperately fussy little old gentlemen leaping out of the water on to the ice, falling flat on their stomachs, but immediately picking themselves up and hurrying towards the ship.

Dressed immaculately in evening dress, with white waistcoat and black coat, somewhat unsteady on their short legs, and therefore balancing themselves with their stiff arms, they strike one at once as having far more human characteristics than any other bird, and one unconsciously gives them mental attributes to suit. These are the little Adélie penguins, about two feet in height and about fifteen to twenty pounds in weight, and they swarm literally in millions round the whole Antarctic continent, spending the winter on the open pack ice and the summer at their breeding haunts, or "rookeries," on some flat point free from snow, and living almost entirely upon the little red crustaceans known as euphausia. Possibly because there are few bare patches of gravel on that continent, but more probably because of an innately gregarious habit of mind, their rookeries number almost millions of individuals. Whole books have been written about their habits, and we must be content here with but a few instances.

Their sole enemy is the sea leopard, which attacks them only in the water, and even then it is not certain that he can always catch them; the consequence is that they are quite fearless on land or ice and will march up to a man with an air of curiosity and an expression of "You're a mighty big penguin, but I am not in the least afraid." They certainly think twice before they enter the water from the rookery, because bitter experience has taught them that their enemy lurks under the ice, waiting for just such careless divers. So if a penguin wants to go out fishing he will settle himself on the edge of the ice-foot and wait patiently for companions, who will turn up by twos or threes, all equally averse from taking the first plunge. If no member of the party can be persuaded by ordinary means, a jostling begins amongst them which sooner or later will end in one being edged over into the water. As soon as that happens the rest peer anxiously to see whether he comes up, and, if so, they all dive in a body after him. If he does not come up, presumably they send a message to the widow and postpone their bathe. Thus they have certain attributes of the genus larrikin, but, when analyzed, there is generally some reason to explain such behaviour. For instance, their nests are made laboriously by collecting pebbles and laying them in a mound, on top of which the eggs are laid without any lining to the nest whatever.

One would say at first sight that pebbles up to an inch in diameter were hardly preferable to bare gravel itself, but the penguin has found that such a mound is the only way to keep the eggs out of the reach of the water from a strong thaw. His collection of pebbles is definitely a private possession of considerable value, since he can carry only one pebble at a time and may have to go several hundred yards for each one. Accordingly, one of his methods of wooing appears to be the gesture of laying a pebble at the feet of his intended, presumably on the principle that a good pebble betokens a good husband. Further, since the nests are built so close together that the sitting birds can almost reach each other, a penguin, in order to reach his or her nest, has to pass literally hundreds of other nests heaped with fine, nobbly pebbles. The result is that the temptation is too great, and the pilfering of pebbles from each others' nests is a universal habit on the rookery, leading to much bickering, if not to real riots, because if only a small difference of opinion commences in amongst the nests, both thief and avenger will wreck the nests they pass by kicking pebbles down. The incidents arising from this habit, which have a human significance, are, of course, legion, and at the same time show some of their mental limitations. One penguin, for instance, having built a nest, decided that he would shift it about ten yards, which meant a whole day's work carrying each pebble singly to the new place. As each pebble was deposited and the labourer turned his back, a neighbouring penguin picked up the pebble and added it to his nest, but the householder never noticed that his house was disappearing brick by brick, and when at the end of the day he had no nest at all he merely seemed grieved and sat disconsolate for several hours.

The young penguins, usually two to a nest, are born to a life which at first consists merely of sleeping, gobbling up crustacea from their mother's beak, and growing fat. Presumably the short season requires this rapid growth and entails a curious habit amongst the older penguins, for as soon as the young ones can stray from their nest it requires both parents' best efforts to keep them fed, and the result is then that at a certain stage a few of the older birds are left on guard amongst the mobs of young ones while all the rest are engaged in filling their crops with food for the young. It soon becomes quite impossible for the parent to find its own young, and it is chased by the nearest group of young ones and pestered till, in desperation, it disgorges the food into those mouths which are most urgent with their shrill appeal. Even so there are still too many young ones for the united efforts of all the parents, and the inevitable result is that those which are less active in chasing the adults for food or less persistent in their cries begin to lose strength and the will to live. Indeed, the predatory skua finds that this stage of the penguin's breeding gives him a myriad opportunities of food, and he has but to wait till some youngster, tired of the ceaseless chasing after food and weary of life in general, wanders away from the guards and from its hateful companions. Then comes a rapid swoop and a quick death to the luckless penguin who has lost in his struggle for survival amongst his fellows.

Those who survive are taught to swim in due course by a few adult birds, and swim away with them in the autumn to winter on the pack ice. Such is the life of the Adélie penguin, curiously adapted to the strange conditions, but that of the other Antarctic penguin is stranger still.

The Emperor penguin, which stands over three feet in height and weighs up to ninety pounds, is, perhaps, the most curious bird in the world. His colouring is rather remarkable, for, instead of the plain white and black of the little Adélie, he has a lemon-yellow chest going through orange up his neck to a brilliant crimson on his beak, and, lacking the white surround to the eye of the smaller bird, he loses something of their similarity to humans. He, too, has no enemies ashore, and his walk is stately, as befits an emperor; his manners are also imperial, if that means deep bows to each other on meeting and yet a certain haughtiness in a group when a strange bird arrives. He, too, could quite easily, as far as we humans can understand, arrange his breeding season for the south in the summer and swim away to the north for the winter; but he does no such thing.

Early in July the Emperors assemble on some sheltered piece of bay ice, which must have two attributes: it must be firm enough not to drift away during the winter, and yet weak enough to break up and float off quite early in the summer. There on the bare ice the eggs are laid with no pretence at a nest, and, as soon as laid, the hooked beak is used to hustle the egg on to the broad black feet, and the incubation is done under a curious flap of skin like an inverted pouch. The chicks, when hatched, are also kept from the cold by being kept in the same place. It must be remembered that at this time of year in the South the gales are almost continuous, the temperature is rarely higher than minus 30° Fahrenheit, and there is complete darkness. Under such conditions Nature has to provide that all the birds of the colony shall have an urgent longing to incubate, for an egg or a chick left about in the open for a few minutes in a blizzard at a low temperature will be lost for ever. Nature's object is, however, not always attained, for the desire is so great that if a chick or an egg is left for an instant it is pounced upon by the nearest three or four birds, whose beaks and whose weight will do the damage even more effectively than the conditions from which they are striving to protect their young.

The excessive zeal of these bulky foster-mothers seems to be the chief reason for the extremely high mortality in the young rather than the extraordinary season of the year, to the rigours of which they are so early exposed. Those that do survive the many mischances of such an upbringing are not sufficiently advanced in plumage or in strength to be able to swim until well into the succeeding summer, and the parents provide for this by arranging that the half-grown young shall sail away to the north on the bay ice as it breaks up in the spring or early summer. The process of setting out on such an insecure raft has been watched, but, on the whole, we do not know very much about the interesting habits of these strange birds, on account of the difficulty of reaching them at that season. A very notable journey was made by Dr. Wilson on the last Scott expedition, together with two companions, to visit and study the Emperors in the depth of winter, which nearly cost the lives of all the party, and the difficulty in reaching the rookery was so great that only one visit could be paid and only three whole eggs recovered. These eggs, the only ones known to science, now repose in the British Museum. Such habits do not strike one as being very suitable even for so tough a bird as the Emperor, but it may, after all, be only foresight on the part of the parents, who, knowing that their young will be exposed to open water conditions before the summer is over, have put forward the season of incubation so that they shall be old enough to cope with these conditions when they arise.

There is one peculiarity about penguins which distinguishes them from all other sea birds, and that is that they have a thick layer of blubber between the skin and the body precisely similar to that of seals and whales. It is interesting to speculate whether this is a normal result of their seeking their food in the same way or whether it is merely Nature's protection from cold for a creature which lacks the power of flight. More generally still, one may seek to divine whether the land animals of the North have been forced to adapt themselves to the conditions by overcrowding elsewhere, or whether they deliberately chose those conditions. The probable answer is that both statements may have been true at different times.

Although it may seem a little discourteous to include human life in a chapter on the plants and animals, no account of the polar regions could be considered complete without some reference to the human inhabitants who, like the animals, may have been forced northwards by pressure of stronger tribes or may have chosen their place of habitation themselves.

The Eskimo are only one of several tribes which habitually live within the Arctic Circle, but they are far more numerous and widely spread than the Siberian tribes, and are more distinctive both in physical characteristics and in mode of life. Their origin is still unsettled, but, whether they came direct from Asia or broke away from the North American Indians and developed special characteristics, they are certainly quite a distinct type now and, indeed, are the hereditary enemies of such Indians in Canada as strayed towards the Arctic Circle. Small and sturdy with straight black hair, they are well fitted physically for the severe conditions under which they live, and they possess an appreciation of conviviality which is almost entirely absent from the true Indian.

They are found all along the coasts of Alaska, Canada, and Labrador, and on Greenland, while the finding of remains of their habitations proves that at one time or another they have inhabited nearly all the islands of the Canadian Archipelago and the north of Greenland, whence they have now disappeared. Altogether there are between 30,000 and 40,000 Eskimo spread over this vast distance, and they have preserved their language and customs so intact that it was possible for Rassmussen, himself partly Eskimo and the chief authority on the race, to journey recently from one end of their domain to the other and find himself at home with and understood by each successive group.

This has probably been due to the fact that everywhere, except in one small part of the Barren Lands of Canada, they have lived by the sea and have carried their original habits and customs along with them as they migrated. How interesting these customs are cannot be shown in so short a reference as this, but accounts of them may be found in the narratives of many expeditions and in special anthropological studies of them.

Their first encounter with Western civilization cannot be taken as a good omen, but that was hardly their fault, for Martin Frobisher was so proud of his discovery of inhabited land that he followed the custom of the age and kidnapped some of the natives to exhibit to Queen Elizabeth, and this incident led to much fighting and distrust for many years. The relations between the races were not improved by the visits of whalers to Davis Strait in later years, but gradually a *modus vivendi* was adopted which persisted until Denmark took West Greenland into her charge, since when the Eskimo have been preserved from too rough a contact with the outer world. Centuries of casual contact with civilization have altered the West Greenland native so much that he is no longer quite true to type, and the same is more or less true of the Alaskan Eskimo; but there are still places in the north of Canada where they are almost entirely untouched by civilization and live in a sturdy independence, fashioning their weapons out of the simple materials used by their forefathers.

These tribes received Stefansson, when he discovered them, without fear or animosity, nor could they be easily persuaded that the inventions of the white man were superior to theirs. Indeed, his attempts to impress them were curiously ineffective. Thus he brought out his telescope and showed them that with it he could recognise caribou at a greater distance than they could with the naked eye. They at once said there was nothing much in that, for they could see them if they walked towards them and invited him to show them an instrument which would see caribou through a hill, for such a magic would indeed be useful to them. Nor were they much impressed with what he could do with a rifle, for, after all, their own weapons attained the same end with considerably less noise. It was, indeed, the careful imitation of their methods which enabled Stefansson to carry out his journeys by hunting, and by even beating the Eskimo at their own mode of life.

Their material culture was always of a high order, for all their implements had to be made out of such materials as were native to the country, with the exception of driftwood, which came from afar. Their skill in the use of bone and wood for weapons, skins and wood for kayaks and oomiaks, leather and sinews for cord and line, is only equalled by their patience and endurance in hunting the animals which form their sole sustenance. In fact, they have adapted themselves so completely to polar conditions that they can be said to be perfectly at home and content under circumstances which it has taken centuries for white men to accustom themselves to even for short periods. This close adaptation to local conditions is nowhere better shown than in their habitations. In the summer they erect dwellings of stone, or turf, or wood, according to the prevalence of each material, and cover them with skins, but in the winter they live in igloos of snow blocks, which they can erect in a few hours and dwell in until the roof wears thin, when they as quickly erect a new one.

The use of snow for semi-permanent dwellings appears to be a strange choice for a land of cold, but it is, in point of fact, an ideal material, and if white men had but studied its value more in the past there would have been fewer tales of tragedy in the Arctic. With a high bench on one side of the igloo and a lamp of seal blubber kept burning, the air, except in the trench for the feet, is kept well above freezing-point and is apt to be too warm instead of too cold. Yet there is sufficient porosity in the snow walls to prevent the air becoming too foul, except possibly to the over-sensitive nostrils of the civilized white man. Such melting of the roof as does take place is absorbed and refrozen by the walls. Moreover, with a net hung to the roof for the drying of wet clothes, skins on the bench for sleeping on, shelves and niches in the walls for odd articles, and the possibility of making alcoves or annexes with an hour's work, the snow igloo is an infinitely more comfortable place than any civilized tent could ever be. Indeed, where they are out of close contact with white men they form communities which in all material ways seem almost ideal. Nor is their mental capacity as primitive as might be expected.

The northward trend of civilization is, nevertheless, spoiling the Eskimo slowly but surely, either by introducing factions and the growth of a commercial spirit or by actually robbing them of the skill of their ancestors and replacing it with mere machines, such as firearms, which they cannot make themselves. Even the sewing machine, which has penetrated to the Eskimo, is not altogether a blessing to them and leads to more rapid but less trustworthy sewing. Yet it will be long before this virile race is altogether destroyed or perverted, and the North still remains one of the few places in the world where friendly yet primitive people can be visited and studied.

CHAPTER V

THE FUTURE OF THE POLAR REGIONS

> Much more in this great work should we survey,
> The plot of situation, and its model,
> Question surveyors, know our estate,
> How able such a work to undertake.
>
> SHAKESPEARE.

WE have seen in our brief study of the conditions in the polar regions that, though they can hardly be called friendly in the full sense of the word, they are to some extent habitable, and they do possess values of one kind or another to a profit-seeking world. Consequently, it is not a matter for surprise that since 1870 the larger Powers have occasionally cast their eyes towards the polar regions with a view to possession. The factor which has been of chief importance in leading nations to this attitude has been the curious turn of affairs in the whaling industry. In the great days of the whalers in the Arctic the world was not ripe for possession in the modern sense of the term. Some of the Arctic islands, such as Spitsbergen, served as a summer rendezvous and a temporary headquarters for the fleets of different nations, but these were satisfied, in general, with some small strip of coast, and, though there was great rivalry at sea when catching whales, there was comparative acquiescence in this temporary ownership of certain bays and harbours.

The whale in the North, being hunted relentlessly and heedlessly, settled the problem by incontinently dying out, and their numbers now are almost insignificant. The industry, therefore, had either to submit to extinction or develop new methods by which the other species of whale, much too active to be taken by open boat whaling, could be captured and turned to profit. The Norwegians have from 1870 led in this new phase of the whaling industry, and the methods which they have now devised are so sure and so wholesale that there is, in the minds of many, a great danger that these whales will share the fate of their cousins. The chief whales belonging to this species are the humpback, the rorqual, and the giant blue whale, the largest mammal in existence. Though they are not truly polar animals, these whales seek the Antarctic pack ice in the southern summer, and it is there, for many reasons, that they are most vulnerable.

In the last ten or fifteen years the increase in whaling in Antarctic waters has been astonishing, and, though exact figures are not available, it appears that from £5,000,000 to £10,000,000 worth of whale products is being taken each season at present. The method of catching these whales is to follow them with a fast whale-catcher, a small boat of 100 tons or so, which is, on the whole, quick enough to follow the whales unless they are really "gallied," or terrified, and yet not too noisy to frighten the whales unduly. By skilful management and inspired guesswork on the part of the skipper the catcher is manœuvred until its bows are within thirty yards or so of a whale just rising to blow. A very large and powerful harpoon gun is then fired from the bows of the ship, and the harpoon penetrates far into the whale's blubber and explodes a bomb, which usually, but not always, kills the whale outright. The rope to which the harpoon is attached is then hauled in, and the carcass of the whale pumped up with air to prevent it sinking, and a flag is planted on it while the catcher goes off to add to its bag. Towards the end of the day the catcher collects its whale carcasses and tows them either to a land blubber station or to a floating factory, a ship of at least 10,000 tons, which is exactly what its name implies.

Usually each " mother ship " will keep from three to six whale-catchers fully occupied. Some of this whaling is now carried on outside territorial waters, but land stations naturally involve possession of the land on which they are built, and many floating factories prefer to work in a harbour which is therefore within territorial limits. The British Government, in an endeavour to restrain the wholesale slaughter of the remaining whales of the world, has claimed two large sectors in the Antarctic, so that it shall be able to issue licences to whaling companies and in some measure maintain a supervision of the industry; but what one nation can do other nations will also like to do, and we find in this present year particularly that claims to various other sectors of the Antarctic continent are being put forward by other nations. The Antarctic, therefore, has now acquired a political significance which nothing but the whaling industry could have justified. Politics in the Arctic is of older date, but cannot be said to be on a much firmer basis, for, where the land claimed is not truly habitable, the old ideas of occupation have to be revised.

Greenland, for instance, as far as its western and south-eastern portions are concerned, belongs by right, both of interest and of occupation, to the Danes. The north-eastern coast, however, visited so far only by occasional exploring expeditions and by hunters, is not yet definitely assigned to anyone. Spitsbergen, to which an old claim by England was long attached, has now been handed over, by common consent of the Powers, to Norway, and seems more than likely to become a possession of value on account of its coal measures. A striking instance of how inapplicable international law may be to polar lands is the case of Wrangel Island, a small island off the north-east corner of Siberia. On the score of proving evidence of possession by occupation, Stefansson sent a party to inhabit the land for two years. Disaster overtook them, though, even so, there could be no doubt as to the occupation being accomplished; but the Soviet settled all arguments by sending a gunboat and imprisoning the claimants. It appears, therefore, that in some parts of the world might may still be right, though at the same time the arguments for the ownership of Wrangel Island by Canada were never very sound. It is to be expected that there will be no such bickering over Antarctic lands, but the fact that there are diplomatic conversations going on about such ownership is evidence that an ice-covered continent may have indirect value, even if it is solely because of the animals which have attempted to take refuge in its inhospitable vicinity.

The mineral resources of the polar regions are slight, not because of the lack of deposits—for such are known—but because of the high cost of retrieving such mineral from a country which is not in any sense self-supporting. Mention should be made, however, of the millions of pounds' worth of fossil ivory which has been recovered from the shores of the new Siberian Islands, where the tusks of mammoths are found by the hundred embedded in the mud and exposed from time to time by new storms. Whether this accumulation of ivory is the result of some vast flood or a world catastrophe, or whether it really indicates that the primeval mammoth, like its present descendant, had its own secret places in which to die, is not known, but the fact remains that Siberia has benefited greatly from what became practically an ivory mine. The coal of Spitsbergen has already been mentioned, and there are other solid deposits yet unworked in both polar regions, but it will be many a long year before polar coal, except in such a position as Spitsbergen, can compete with that of temperate regions. Of precious metals nothing more than encouraging reports have been received, but an interesting mineral called cryolite, useful, and, in fact, essential, in the recovery of aluminium, has been mined for many years on the west coast of Greenland. In the Antarctic no minerals except coal have yet been discovered. It is, in fact, clear that nothing short of a "Bonanza" mine in such regions would ever pay the costs of recovery.

The polar regions, therefore, except for their animal life, cannot claim any real economic value for civilization, and, although guided by the enthusiasm of Stefansson, fuller use will certainly be made of those Arctic lands which will support reindeer, it cannot be said that there is a great future even for pastoralists in the polar regions proper.

It may be somewhat disappointing to a world which is always looking for economic values and feeling itself hungry for new lands to read that the polar regions do not offer much either in dividends or in real estate, but such seems to be the case even in the North, and most certainly so in the South, where the nearest approach to permanent settlement will never go beyond provision of permanent meteorological stations and perhaps some sanatoria. This suggestion is not as exaggerated as it may sound, for, when safe transport by air becomes common, there is no reason why the jaded citizens of the Southern Hemisphere should not seek health and vigour by flying to some favoured spot on the southern continent, where doctors and hotel managers shall minister to their needs, and an atmosphere entirely free from germs shall cure their ailments. In the Arctic, surrounded as it is by well-populated countries, there is a certain, if dim, future as an airway, a future which is already being investigated in some detail; and the southern end of Greenland, in particular, will probably have its landing stations in the future and serve as a part-way house on the shortest route between Northern Europe and Northern America.

But if the economic value of the polar regions is thus strictly limited, the same cannot be said of its scientific value, and it will be at least a century or two before the geographer, the geologist, and the meteorologist will be able to say that they have got all the data they require from those parts of the world. The scientific problems of these regions are, indeed, so vast that they can hardly be said to have been even fully stated. How far is the weather of habitable lands affected by the meteorology of the polar caps? What is the solution to the riddle of coal beds and other evidence of warm climates in the past at the poles? How far is the present Age of Ice on the Antarctic continent comparable to the last invasion of ice over Europe and America? These and other questions, some of them even with an economic aspect, are continually being asked by leaders in science, and the answers are certainly only to be found by repeated visits to the regions, so that the real end of polar exploration will be very long in coming. The world, in fact, must continue to be interested in the polar regions.

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